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OPTIMAL DSST INPUT DECKS FOR VARIOUS ORBIT TYPES

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Final Report

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14. Abstract This paper describes optimal input decks for Draper Semianalytic Satellite Theory (DSST) for various orbit types. These input decks are optimized to balance the trade-off between accuracy and computation time. Input decks for low, medium, and high altitude circular, near earth eccentric, Molniya, and geosynchronous orbit types are given. Accuracy metrics are derived from fits to simulated data generated by a Cowell truth model. Timing measurements are obtained by a call to an internal clock routine immediately prior to and subsequent to execution. The PC based version of R&D GTDS provides the testbed for this analysis.

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Artificial Satellites, Orbit Propagation, Semianalytic Satellite Theory, Perturbations, Draper Laboratory

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NOMENCLATURE

AAS	American Astronautical Society
AIAA	American Institute of Aeronautics and Astronautics
AOG	DSST Averaged Orbit Generator
B*	SGP4 Drag Parameter
C_D	Coefficient of Drag
cm	Centimeters
C_R	Solar Radiation Pressure Parameter
DC	Differential Correction
deg	Degrees
DSST	Draper Semianalytic Satellite Theory
EG	Ephemeris Generation
er	Earth Radii
ETAS	The Ephemeris Theory Accuracy Study
GEM	Goddard Earth Model
GEO	Geosynchronous Case
GRAV	Refers to Geopotential Modelling in AOG (see page 5)
HACC	High Altitude Circular Case
H-P	Harris Priester Drag Model
JGM	Joint Gravitational Model
J-R	Jacchia-Roberts Drag Model
kg	Kilograms
km	Kilometers
LACC	Low Altitude Circular Case
L-S	Lunar/Solar Third Body Point Mass Effects
m	Meter
MACC	Medium Altitude Circular Case
MOLY	Molniya Case

NEEC	Near Earth Eccentric Case
OD	Orbit Determination
ORB1	A GTDS File Containing Evenly Spaced, Time-Tagged Values of Position and Velocity
PC	Personal Computer
PL/VTA	Astrodynamics Division, Phillips Laboratory
R&D GTDS	Draper Laboratory's Version of the Goddard Trajectory Determination System
R_e	Radius of the Earth
RESNM	GTDS Keyword to Include Resonant Terms in AOG (see page 5)
RESONPRD	GTDS Keyword to Adjust Modelling of Resonance Between AOG and SPG (see page 5)
RMS	Root Mean Square
SATCAT	Satellite Catalog
sec	Seconds
SMAH	Semimajor Axis Height ($a - R_e$)
SPG	DSST Short Periodic Orbit Generator
SRP	Solar Radiation Pressure
SPSHPER	Keyword in R&D GTDS for Global Short Periodic Selection
SSTAPGFL	Keyword to establish AOG partial derivatives for various force model options
SSTESTFL	Keyword to control the matrix partitioning of DSST partial derivatives (AOG & SPG)
TESS	Refers to the Tesseral Linear Combination Short Periodic Modelling in SPG (see page 5)
VOP	Variation of Parameters
WTD	Weak Time Dependence

Summary

Objectives: The objective of this research was to develop input configurations for the Draper Semianalytic Satellite Theory (DSST) which provide a balance between computational speed and ephemeris accuracy. This research follows VTA's efforts in 1994 to port the software system containing DSST (Draper Research and Development Goddard Trajectory Determination System, R&D GTDS) from a UNIX-based platform to a Windows/DOS environment (486 and Pentium). These input decks, which are required to properly run the software, have been developed for distribution along with a complete mathematical description of theory (the description was developed by the Naval Postgraduate School with assistance from Draper Laboratory). Optimal input decks were developed for low, medium, and high altitude circular, geosynchronous, Molniya, and near earth eccentric orbits.

Approach: In order to determine the proper configurations for the theory, various batch, differential correction fits to simulated observational data were performed. The results of these various fits were then compared in terms of accuracy and computational efficiency to operational orbit determination capabilities. Selection of appropriate input deck configurations was based on attaining speeds comparable to operational algorithms while maintaining at least a 5-10 fold increase in ephemeris accuracy.

Alternative Technologies: Various alternative technologies for orbit determination (OD) are available; these OD technologies can be compared based on the orbit propagation technique used. Classically, orbit propagation has been categorized as either numeric (very high accuracy with slow run times) or analytic (very fast with severely limited accuracy). DSST represents a hybrid approach which combines the advantageous aspects of both numeric and analytic theories (accuracies approaching that of numeric methods with speeds comparable to analytic techniques). DSST, developed by Dr. Paul Cefola and his colleagues at the Charles Stark Draper Laboratory, is the state of the art in American semianalytic techniques.

Technical Challenges: VTA has had to combat (1) a limited knowledge base concerning the cutting edge astrodynamic techniques of DSST and (2) a lack of knowledge of how to properly run the software with potential users.

Payoffs: DSST will be used by various research and operational based institutions. Currently, DSST is slated for operational use with the RADARSAT mission (work accomplished by Draper Laboratory), the Air Force Maui Optical Station (AMOS), and the STARFIRE facility. VTA has been using R&D GTDS to support operational orbit determination experiments for the past eight months. Specifically, dark pass satellite illumination has been accomplished. Kaman Sciences has been using the input decks for their Space Command supported Ephemeris Theory Accuracy Study. The Naval Postgraduate School has been using results generated with the input decks to increase Navy Space Command's understanding of semianalytic techniques.

Results: For the first time, input decks to balance computational speed and ephemeris accuracy have been documented. This gives the user with limited knowledge concerning the intricacies of DSST a better chance at *properly* running the software.

1.0 Introduction

Various studies in the past twenty years have demonstrated the accuracy, computational efficiency, and flexibility of DSST for a variety of orbit types[1-24]. These encouraging results have led to a proliferation of the theory to various academic and research based institutions. In most cases, DSST has been distributed as part of the larger scale R&D GTDS orbit determination system, which also includes the Cowell[32], SGP[25], SGP4/ SDP4[25,26,27], HANDE[28], SALT[29,30,31], Brouwer Lyddane[32], and Vinti[32] orbit propagation theories (the addition of PPT2 to R&D GTDS is nearing completion as of the date of publication of this document). In addition to these orbit propagation theories, R&D GTDS includes estimation (batch & filter), early orbit determination, data simulation, and error analysis programs[32]. These programs give R&D GTDS the flexibility to compare the performance of various orbit propagation theories.

Recent efforts have unified DSST's theoretical documentation from a multitude of AIAA/AAS papers, journal articles, contract reports, laboratory memorandums, and working notes to a single document[1]. The knowledge of how to *properly* run the software, however, has not been as easily grasped by the community. The addition of the Semianalytic Input Processor to the software has provided a tool which simplifies the configuration of DSST's SPG[33]. This document sheds light on how to best use the tool.

Specifically, this paper contains a set of DSST input decks which balance accuracy and computational efficiency for a variety of orbit types. These configurations span the orbit classes established by Kaman Sciences in the Ephemeris Theory Accuracy Study (ETAS)[5]. These configurations can be inserted into the code for automatic set-up of the theory, or used in a standalone fashion by the traditional R&D GTDS user. The information in this paper, when coupled with the description of the theory[1], provides current and potential users with a concise package which supports R&D GTDS.

One final note before each specific orbit class is described in detail is that two separate machines were used for the generation of results herein (both a 486 and a Pentium 586 machine were used). Therefore, from case to case, timing statistics may not seem consistent; however, within one particular case, the results are consistent. In addition, most cases used a spacecraft cross-sectional area of 1 m^2 and a mass of 100 kg. Even though these values may not exactly match the parameters for the actual, "real-world" spacecraft, they were chosen to represent a standard area to mass ratio. Furthermore, appendices are attached which provide the information necessary to replicate test cases with the optimal input decks.

2.0 Low Altitude Circular Case (LACC)

An orbit very close to decay was chosen to fulfill the low altitude circular test case. In the ETAS study, the LACC is characterized by a SMAH range of 0 - 575 km and an eccentricity range from 0.0 to 0.05. For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a 90 minute arc. A 90 minute DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 450 seconds.

The osculating elements required for the Cowell truth EG were built from a one day DSST run with the following inputs:

Table 1. DSST Specifics to Build Osculating Elements, LACC

Epoch Date YYMMDD HHMMSS.S	820223 000000.0
End Date YYMMDD HHMMSS.S	820224 000000.0
Semimajor Axis (mean)	6635.0814 km
Eccentricity (mean)	0.010201164

Table 1. DSST Specifics to Build Osculating Elements, LACC (Continued)

Inclination (mean)	64.9567 deg
Longitude of Ascending Node (mean)	228.6393 deg
Argument of Perigee (mean)	271.2229 deg
Mean Anomaly (mean)	88.164558 deg
Input Frame	True of Date
Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	4th Order Runge-Kutta
DSST Step Size	43200.0 sec
Gravity Field	8x8 GEM10B
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts $C_D = 2.0$
Solar Radiation Pressure	No
Global Short Periodic Select	Low Altitude, Improved Accuracy Option (SPSHPER = 3)
Average Spacecraft Cross-Sectional Area	1.0 m^2
Spacecraft Mass	100 kg

The osculating elements which resulted from this one day DSST run were then used as inputs for a six day Cowell EG. The specifics for this Cowell EG are given in Table 2:

Table 2. Cowell Truth EG Inputs, LACC

Epoch Date YYMMDD HHMMSS.S	820224 000000.0
End Date YYMMDD HHMMSS.S	820302 000000.0
Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	12th Order Summed Cowell/ Adams Predict-Partially Correct
Step Size	60.0 sec
Gravity Field	21x21 GEM10B
Lunar / Solar Point Masses	Yes

Table 2. Cowell Truth EG Inputs, LACC (Continued)

Drag Model	Jacchia-Roberts $C_D = 2.0$
Solar Radiation Pressure	No
Average Spacecraft Cross-Sectional Area	$1.0 \, m^2$
Spacecraft Mass	100 kg

It can be noted in this table a six day Cowell EG was created, even thought the fit and predict spans totalled 180 minutes (in other words, more ORB1 data was generated than was required). This test procedure was established to provide enough data if subsequent testing with other fit and predict spans was desired. The output of this EG indicated the satellite would re-enter the atmosphere three days after the Cowell epoch (this particular test case reflects an orbit extremely close to decay). Due to the short remaining orbital lifetime for this satellite, it was determined that fit and predict spans on the order of the satellite's period should be used. This test protocol was deemed analogous to operational procedures for a satellite this close to re-entering the atmosphere.

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in Table 3:

Table 3. DSST DC Specifics, LACC

Epoch Date YYMMDD HHMMSS.S	820224 000000.0
Fit Span Begin YYMMDD HHMMSS.S	820224 000000.0
Fit Span End YYMMDD HHMMSS.S	820224 013000.0
Semimajor Axis (mean)	6628.457 km
Eccentricity (mean)	0.0089
Inclination (mean)	64.84 deg
Longitude of Ascending Node (mean)	224.51 deg
Argument of Perigee (mean)	271.89 deg
Mean Anomaly (mean)	115.16 deg
DSST Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
DSST Step Size	43200.0 sec
Geopotential Model	GEM10B
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the LACC are given in Table 4; however, it is first desirable to describe some of the notation used in this table (and other tables in this paper):

- GRAV refers to the geopotential modeling in the AOG.
- RESONPRD is a GTDS keyword for the input processor to override the default boundary for the modeling of tesseral resonance in the AOG (if the period of the resonance is less than 10 days in the default configuration, the resonance is modelled in the SPG as a tesseral linear combination high frequency term); by specifying a value with this keyword, a new boundary can be set to force the modeling of resonance into the AOG (i.e., for shallow resonance).
- RESNM is a GTDS keyword for the input processor to include resonant harmonics in the AOG. Typically, this card is used to augment a small "base" gravity field (i.e., 4x4) specified with MAXDEGEQ and MAXORDEQ cards with resonant harmonics beyond the "base" field (for example, the 16th order). It should be noted the RESNM card eliminates the need for a RESONPRD card; all harmonics specified with the RESNM card are forced into the AOG (even shallow resonance). For this particular case, an 8x8 base field was established and the RESNM card was used to include resonant effects at the 16th and 17th orders (an AUTOFORC card must be used with RESNM).
- TESS refers to the tesseral linear combination high frequency short periodic terms.
- SRP is an abbreviation for solar radiation pressure.
- J-R is an abbreviation for the Jacchia-Roberts atmospheric density model.
- H-P is an abbreviation for the Harris-Priester atmospheric density model.
- L-S is an abbreviation for lunar / solar third body point mass effects.
- "trunc" refers to truncated modeling; modeling descriptions corresponding to the R&D GTDS Semianalytic Satellite Theory input processor are specified where needed. Additional details can be found in the R&D GTDS Semianalytic Theory Input Processor keyword description booklet[33].
- **Total Position RMS is derived over the 90 minute predict span only** (from the R&D GTDS Ephemeris Comparison Program).
- R&D GTDS default configuration settings are used unless specifically noted.
- "Iszak" refers to Iszak's J_2 height correction (a second order atmospheric drag effect included in AOG partials). All cases which attempt to solve for C_D include first order drag effects in the AOG partials (as well as Iszak's corrections if indicated; if C_D is not solved for, then all drag partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- Most cases have an SSTESTFL card of 1 3; this setting includes all desired AOG partials in the A matrix (J_2 partials are computed analytically; all other partial derivatives are computed via finite differences). In addition, this setting includes desired AOG partial derivatives for non-conservative perturbations in the D matrix via finite differences (these partials were also included in the A matrix). Cases noted by ** have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences (with this setting, third body and J_2^2 AOG partial derivatives, if desired, would not be included anywhere; if they are desired, the SSTESTFL setting of 1 3 should be used).

Table 4. DSST DC and Subsequent EG Results, LACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	DC DIVERGES		
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Iszak Solve C_D	No	L-S AOG SPG	54.62 sec	3.01 meters (6 its)	33.960 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Iszak Solve C_D	No	L-S AOG SPG	54.33 sec	2.66 meters (6 its)	34.034 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Iszak Solve C_D	No	No	53.83 sec	2.81 meters (6 its)	34.168 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG Iszak Solve C_D	No	No	45.36 sec	77.12 meters (4 its)	163.31 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	No	No	No	46.26 sec	207.81 meters (5 its)	5238.7 meters

Table 4. DSST DC and Subsequent EG Results, LACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2	Yes	Yes	No	Yes	Yes	J-R AOG SPG Iszak Solve C_D	No	No	31.36 sec	50.59 meters (5 its)	216.51 meters
21x21 J_2^2	Yes	No	No	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	17.19 sec	32.71 meters (5 its)	468.24 meters
21x21 J_2^2	Yes	No	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	35.53 sec	50.16 meters (5 its)	309.45 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	39.16 sec	3.62 meters (6 its)	31.292 meters
12x12 J_2^2	Yes	Yes	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	21.64 sec	8.39 meters (6 its)	87.282 meters

Table 4. DSST DC and Subsequent EG Results, LACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
12x12 J_2^2	Yes	Yes	trunc 8 8 4 2 -12 12	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	19.28 sec	10.17 meters (6 its)	58.072 meters
12x12 J_2^2	Yes	Yes	trunc 4 4 4 2 -8 8	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.81 sec	22.16 meters (5 its)	198.45 meters
8x8 J_2^2	Yes	Yes	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	17.56 sec	18.30 meters (5 its)	58.201 meters
8x8 J_2^2	Yes	Yes	trunc 6 6 4 2 -10 10	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.80 sec	17.40 meters (5 its)	65.710 meters
8x8 J_2^2 * * (opt. deck)	Yes	Yes	trunc 6 6 4 2 -10 10	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.31 sec	17.40 meters (6 its)	65.720 meters

Table 4. DSST DC and Subsequent EG Results, LACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2	trunc 4 2 4	Yes	trunc 6 6 4 2 -10 10	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.91 sec	18.25 meters (5 its)	60.651 meters
8x8 J_2^2	trunc 4 2 4	trunc 4 4 2	trunc 6 6 4 2 -10 10	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.48 sec	23.15 meters (5 its)	291.89 meters
8x8 J_2^2	Yes	Yes	trunc 4 4 4 2 -8 8	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.42 sec	30.89 meters (5 its)	123.48 meters
8x8 J_2^2	Yes	Yes	trunc 2 2 4 2 -6 6	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	15.87 sec	34.75 meters (5 its)	211.94 meters
8x8 J_2^2	Yes	Yes	trunc 2 2 4 2 -6 6	Yes	No	J-R AOG SPG Solve C_D	No	No	15.98 sec	34.76 meters (5 its)	212.44 meters
8x8 J_2^2 16th order RESNM	Yes	Yes	trunc 2 2 4 2 -6 6	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	15.98 sec	35.28 meters (5 its)	209.94 meters

Table 4. DSST DC and Subsequent EG Results, LACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2/ m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2 16 & 17 th order RESNM	Yes	Yes	trunc 2 2 4 2 -6 6	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.20 sec	34.90 meters (5 its)	214.43 meters
6x6 J_2^2	Yes	Yes	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.64 sec	15.22 meters (5 its)	143.55 meters
6x6 J_2^2	Yes	Yes	trunc 4 4 4 2 -8 8	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.14 sec	27.83 meters (5 its)	86.261 meters
6x6 J_2^2	Yes	Yes	trunc 2 2 4 2 -6 6	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	15.60 sec	36.55 meters (5 its)	364.52 meters
4x4 J_2^2	Yes	Yes	Yes	Yes	No	J-R AOG SPG Iszak Solve C_D	No	No	16.09 sec	22.46 meters (5 its)	332.57 meters

Table 4. DSST DC and Subsequent EG Results, LACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
Space Command's SGP (solve for drag term ndot/2)									13.29 sec	1182.50 meters (4 its)	12605.0 meters
Space Command's SGP4 (solve for drag term ndot/2)									13.35 sec	138.64 meters (5 its)	505.19 meters

The results in Table 4 enforce some important concepts for low earth orbits. First, large effects stem from atmospheric drag, tesseral m-dailies, and tesseral linear combination short periodics. In fact, attempting to even slightly truncate the drag or m-daily modeling greatly impacts the accuracy. On the contrary, these results indicate the tesseral linear combination short periodic modeling can be truncated to vastly improve the computation time with an acceptable degradation of accuracy (for most applications).

Specifically, the following errors can be noted for a one revolution predict:

- removing drag entirely results in ~ 5 km error
- drag short periodics ~ 130 m error
- tesseral m-dailies ~ 300 m error
- removing all tesseral linear combination short periodic terms ~ 200 m error

These results also indicate the J_2 / m-daily model serves to provide accuracy closure with Cowell, but at an expense of computation time. For reasons of simplicity and computational time savings, this model can be neglected in an optimized DSST configuration.

Third body effects were determined to not significantly impact these orbits. Specifically, the inclusion of these effects does not dramatically improve accuracy or greatly increase computer run time. For reasons of simplicity, their effects can also be neglected in an optimized DSST configuration for this orbit type.

Several comments can be made about the short nature of these runs (90 minute fit and predict spans). Short fit spans can lead to "observability" problems when the DC attempts to solve for drag terms (or any other desired solve for parameter, i.e. station biases). These "observability" problems result because the DC can not sample or observe a large arc of the satellite's trajectory, which makes it difficult to discern or separate the various contributions to the satellite's motion. For analytic theories, these observability problems are compounded by their limited physical force models. To deal with observability problems or a lack of physical force models, longer fit spans are usually employed; however, longer fit spans may not be practical or even possible for decay orbits. For these reasons, only complete perturbation theories should be used to process decay orbits. It should also be mentioned the short nature of these runs negated the benefit of special shallow resonance processing for the truncated geopotential cases (i.e., RESONPRD and RESNM).

As the *Approach* section of the *Summary* on page 1 states, the selection of appropriate input deck configurations was based on attaining speeds comparable to operational algorithms while maintaining at least a 5-10 fold increase in ephemeris accuracy. The results for this particular test case and test methodology indicate that several of the DSST configurations very nearly meet this criteria (the timing statistics fall short of the desired criteria by 20-30 percent).

Testing was done to try to simulate real-world uncertainties with atmospheric drag. In these tests, a Jacchia-Roberts drag model was used to generate a Cowell truth EG. Then, a Harris-Priester DSST configuration was fit over a 90 minute arc to the Jacchia-Roberts Cowell truth trajectory (in these cases, either the default Harris-Priester table with F#=150 or the "hottest" table with F#=275 in R&D GTDS was used). Again, a 90 minute predict span followed the fit span, with accuracy metrics derived over both the fit (DC RMS) and predict spans (R&D GTDS Ephemeris Comparison Program). The results of this testing are presented in Table 5:

Table 5. Simulation of Real World Drag Uncertainties, LACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2 (opt. deck) **	Yes	Yes	trunc 6 6 4 2 -10 10	Yes	No	H-P AOG SPG Iszak Solve C_D F#=275	No	No	15.87 sec	16.29 meters (6 its)	150.97 meters
8x8 J_2^2 (opt. deck) **	Yes	Yes	trunc 6 6 4 2 -10 10	Yes	No	H-P AOG SPG Iszak Solve C_D F#=150	No	No	15.73 sec	24.68 meters (6 its)	311.96 meters

Note the configurations listed in Table 5 are designated as "opt. deck" even though they use the Harris-Priester atmospheric model (the optimal configuration uses the Jacchia-roberts atmospheric model). This designation was given because all geopotential, partial derivative, solve-for, and force model options for the AOG and SPG match the optimal configuration (even though the particular atmospheric model may be different).

The setup for the LACC which provides an optimal balance between accuracy and computational speed can now be given (opt. deck):

- 8x8 geopotential (AOG)
- J_2^2 (AOG and SPG)
- Zonal short periodics with default settings
- M-daily short periodics with default settings
- Truncated tesseral linear combination high frequency short periodics (SPTESSLC = 6 6 4 2 -10 10)
- Jacchia-Roberts drag (AOG and SPG)
- Solve C_D
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 1.0 6.0 0.0

Sample input decks for the LACC are given in the appendices.

3.0 Medium Altitude Circular Case (MACC)

A Landsat type orbit was chosen to fulfill the medium altitude circular orbit test case. In the ETAS study, the MACC is characterized by a SMAH range of 575 - 1000 km and an eccentricity range from 0.0 to 0.05. For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a three day arc. A three day DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 450 seconds (a 45 minute time interval was used in the R&D GTDS Ephemeris Comparison Program).

The osculating elements required for the Cowell truth EG were built from a one day DSST run with the following inputs:

Table 6. DSST Specifics to Build Osculating Elements, MACC

Epoch Date YYMMDD HHMMSS.S	820223 000000.0
End Date YYMMDD HHMMSS.S	820224 000000.0
Semimajor Axis (mean)	7077.787 km
Eccentricity (mean)	0.011542
Inclination (mean)	98.250452 deg
Longitude of Ascending Node (mean)	158.15349 deg
Argument of Perigee (mean)	89.4 deg
Mean Anomaly (mean)	312.90205 deg
Input Frame	True of Date
Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	4th Order Runge-Kutta
DSST Step Size	43200.0 sec
Gravity Field	8x8 GEM10B
Lunar / Solar Point Masses	Yes
Drag Model	No
Solar Radiation Pressure	No

The osculating elements which resulted from this one day DSST run were then used as inputs for a six day Cowell EG. The specifics for this Cowell EG are given in Table 7:

Table 7. Cowell Truth EG Inputs, MACC

Epoch Date YYMMDD HHMMSS.S	820224 000000.0
End Date YYMMDD HHMMSS.S	820302 000000.0

Table 7. Cowell Truth EG Inputs, MACC (Continued)

Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	12th Order Summed Cowell/ Adams Predict-Partially Correct
Step Size	60.0 sec
Gravity Field	21x21 GEM10B
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts $C_D = 2.0$
Solar Radiation Pressure	No
Average Spacecraft Cross-Sectional Area	$1.0\ m^2$
Spacecraft Mass	100 kg

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in the following table:

Table 8. DSST DC Specifics, MACC

Epoch Date YYMMDD HHMMSS.S	820224 000000.0
Fit Span Begin YYMMDD HHMMSS.S	820224 000000.0
Fit Span End YYMMDD HHMMSS.S	820227 000000.0
Semimajor Axis (mean)	7077.8 km
Eccentricity (mean)	0.0011
Inclination (mean)	98.2 deg
Longitude of Ascending Node (mean)	158.1 deg
Argument of Perigee (mean)	89.4 deg
Mean Anomaly (mean)	176.0 deg
DSST Input Frame	True of Date
DSST Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
DSST Step Size	43200.0 sec
Geopotential Model	GEM10B
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the MACC are given in Table 9; again, it is first desirable to describe some of the notation used in this table (and other tables in this section):

- GRAV refers to the geopotential modeling in the AOG.
- RESONPRD is a GTDS keyword for the input processor to override the default border for the modeling of tesseral resonance in the AOG (if the period of the resonance is less than 10 days in the default configuration, the resonance is modelled in the SPG as a tesseral linear combination high frequency term); by specifying a value with this keyword, a new border can be set to force the modeling of resonance into the AOG (i.e., for shallow resonance).
- TESS refers to the tesseral linear combination high frequency short periodic terms.
- SRP is an abbreviation for solar radiation pressure.
- J-R is an abbreviation for the Jacchia-Roberts atmospheric density model.
- H-P is an abbreviation for the Harris-Priester atmospheric density model.
- L-S is an abbreviation for lunar / solar third body point mass effects.
- trunc refers to truncated modeling; specifically, the maximum power of the eccentricity was set to 2 and the maximum frequency in true longitude was set to 11 in Fourier coefficients for these short periodic expansions[33].
- **Total Position RMS is derived over the three day predict span only** (from the R&D GTDS Ephemeris Comparison Program).
- All cases which attempt to solve for C_D include first order drag effects in the AOG partials (if C_D is not solved for, then all drag partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- Most cases have an SSTESTFL card of 1 3; this setting includes all desired AOG partials in the A matrix (J_2 partials are computed analytically; all other partial derivatives are computed via finite differences). In addition, this setting includes desired AOG partial derivatives for non-conservative perturbations in the D matrix via finite differences (these partials were also included in the A matrix). Cases noted by ** have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences (with this setting, third body and J_2^2 AOG partial derivatives, if desired, would not be included anywhere; if they are desired, the SSTESTFL setting of 1 3 should be used).

Table 9. DSST DC and Subsequent EG Results, MACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG	No	L-S AOG SPG	232.83 sec	23.50 meters (6 its)	248.76 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG	No	L-S AOG SPG	311.6 sec	9.38 meters (9 its)	260.40 meters

Table 9. DSST DC and Subsequent EG Results, MACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	674.48 sec	13.18 meters (23 its)	212.13 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	317.14 sec	9.20 meters (9 its)	236.57 meters
21x21 J_2^2 RESON PRD = 2 days	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG	No	L-S AOG SPG	310.44 sec	8.28 meters (9 its)	259.63 meters
21x21 J_2^2 RESON PRD = 2 days	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	393.10 sec	7.75 meters (12 its)	241.01 meters
4x4 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG	No	L-S AOG SPG	47.29 sec	123.48 meters (7 its)	342.54 meters
4x4 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	52.98 sec	117.47 meters (8 its)	386.02 meters
8x8 J_2^2	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	72.72 sec	71.15 meters (7 its)	261.57 meters

Table 9. DSST DC and Subsequent EG Results, MACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2/ m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2	Yes	Yes	No	Yes	Yes	J-R AOG SPG Solve C_D	No	L-S AOG SPG	46.68 sec	92.70 meters (7 its)	279.60 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	No	L-S AOG SPG	41.47 sec	92.96 meters (7 its)	277.11 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	No	L-S AOG SPG	40.26 sec	92.95 meters (7 its)	276.77 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	Yes	No	J-R AOG Solve C_D	No	L-S AOG SPG	39.33 sec	92.95 meters (7 its)	276.77 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	Yes	No	J-R AOG Solve C_D	No	L-S AOG	38.06 sec	92.92 meters (7 its)	276.70 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	No	No	J-R AOG	No	L-S AOG	33.83 sec	97.50 meters (7 its)	259.80 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	No	No	J-R AOG Solve C_D	No	L-S AOG	37.08 sec	93.06 meters (7 its)	278.26 meters
8x8 J_2^2 * *	trunc 8 2 11	trunc 8 8 2	No	No	No	J-R AOG Solve C_D	No	L-S AOG	34.28 sec	93.06 meters (7 its)	278.30 meters

Table 9. **DSST DC and Subsequent EG Results, MACC (Continued)**

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 * * RESON PRD = 1 day (opt. deck)	trunc 8 2 11	trunc 8 8 2	No	No	No	J-R AOG Solve C_D	No	L-S AOG	35.31 sec	76.51 meters (7 its)	196.85 meters
Space Command's SGP4 (solve for drag term ndot/2)									28.67 sec	581.68 meters (5 its)	1412.3 meters
Space Command's SGP4 (do not solve for drag term ndot/2) B* = 0.0001 er^{-1}									36.03 sec	905.98 meters (12 its)	17876.0 meters

The results in this table indicate that when fitting an optimized version of DSST to simulated data for the MACC, solving for C_D appears to make the results worse. However, solving for C_D in the "full-up" DSST cases leads to results which are more accurate than in the analogous case in which C_D is not solved for. This phenomena can be accredited to the decreased modeling in the optimized DSST configuration. Specifically, error characteristics resulting from perturbations other than atmospheric drag may bias the drag effect. For example, the drag model in DSST may attempt to account for error signatures in the semimajor axis which stem from un-modeled tesseral resonance; the reduced modeling makes it more difficult for the OD system to separate which source perturbing effects are coming from. If C_D is not solved for in these cases, its value defaults to the same value used in the generation of the truth ephemeris; hence, better results can be expected in these controlled experiments if C_D is not solved for. In real world analysis, the actual value of C_D may not be known very accurately, which necessitates a solution for C_D.

Clearly, the modeling of the tesseral short periodics can be truncated to greatly reduce the computer run time. In fact, for the 8x8 case in which the tesseral short periodics have been turned off, a 36% savings in computer run time is gained at the expense of an approximate 20 meter fit and predict difference (as compare to the 8x8 case with a full tesseral short periodic model). Similarly, the zonal and m-daily short periodic modeling can be slightly truncated to benefit the computer run time without a significant loss of accuracy. Third body and drag short periodics can be removed to enhance run time with no degradation in accuracy.

Both the J_2^2 and the J_2 / m-daily model serve to provide accuracy closure with Cowell, but at an expense of computation time. For reasons of simplicity and computational time savings, these models can be neglected in an optimized DSST configuration.

The period of resonance for the 14th order is less than two days (approximately 1.84 days), while the period of resonance for the 15th order is less than three days (approximately 2.18 days). Therefore, running R&D GTDS **without** a RESONPRD card to change the default resonance border from ten days would force the shallow resonance terms at these orders into the tesseral linear combination model of the SPG. A RESONPRD card setting the resonance border at one day forces the shallow resonance terms at both the 14th and 15th orders into the AOG. Using RESONPRD with a value of two days only puts the 15th order shallow resonance into the AOG. As is shown in the results using a "full" 21x21 geopotential field, modeling resonance in the AOG provides for modest improvements in fit span accuracy over modeling resonance in the SPG. However, improvements in predict span accuracy are not necessarily gained. With the optimized version of DSST, almost 100 meters worth of improvement in predict accuracy is gained by including the resonant terms at the 14th and 15th orders in the AOG (as opposed to neglecting these terms with an optimized version of DSST using an 8x8 base gravity field. It should be noted some of this improvement can be attributed to the increased AOG zonal modeling which results from the method used to include the shallow resonance terms--refer to the following paragraph for details of this method). As a general rule of thumb, it is probably better to have resonance modeled in the AOG due to the nature of the theory. In this manner, resonance is captured in the mean equations of motion and handled numerically (which tends to provide better treatment of the non-linearities and large magnitudes associated with resonance).

It is of particular **importance** to use extreme care when running an optimized version of the DSST. For example, if the tesseral linear combination high frequency short periodics have been truncated or removed for an orbit in which shallow resonance occurs, resonance terms will be totally neglected (assuming a resonant period < 10 days and no adjustment with the RESONPRD card). In these cases, the user must experiment with the AUTOFORC and RESNM cards or the RESONPRD card and hand calculation of the resonant periods to ensure the appropriate resonance modeling occurs (which can become quite tedious). As an alternative, the user can specify a 21x21 gravity field with truncated or no tesseral linear combination short periodics and a RESONPRD of one day. This would include all shallow resonant terms (and obviously deep resonant terms) with a period greater than one day into the AOG at the expense of additional secular and long period zonal calculations in the AOG. This configuration, which is used in the MACC optimal deck, is much simpler than experimenting with the AUTOFORC and RESNM cards or hand calculation of resonant period (which is not practical for operational scenarios with multiple satellites). For example, an 8x8 base gravity field could have been established for the MACC along with AUTOFORC and RESNM cards to include all the resonant terms at the 14th and 15th order (which requires 1 AUTOFORC card and 15 RESNM cards). This configuration would not introduce any secular and long period zonal calculations in the AOG beyond the 8x8 base gravity field. However, for only a 3% increase in computer run time (35.31 seconds versus 34.28 seconds), the 21x21 configuration with a RESONPRD of one day can be used (which does introduce secular and long period zonal calculations in the AOG beyond the 8x8 base gravity field up to the 21x21 limit) and remove the introduction of 16 R&D GTDS keyword cards. This example shows the generality and efficiency with which the recursions handle the calculation of zonal effects in the AOG (it should be noted the same recursion concept is used for all portions of the geopotential in the AOG and SPG).

This general handling of resonant terms becomes extremely useful when considering multiple satellites under the broad definition of the MACC. Instead of introducing costly "man-in-the-loop" calculations, this general configuration efficiently captures resonant terms (shallow and deep) for all orbits in the MACC (up to the 21x21 limit; note that the same general concept can be used with the 50x50 version of R&D GTDS).

The initial drag results led to some further processing with the Harris Priester drag model. In contrast to the Jacchia-Roberts drag model, the Harris-Priester model can be considered "static" in nature. The "dynamic" Jacchia-Roberts model implements "observed" or predicted values for drag-related parameters (solar flux and geomagnetic data). The Harris-Priester model implements established "look-up" tables to obtain drag-related parameters (altitude versus density). In this manner, the Harris-Priester model presents a "smoother" or more stable picture of the atmosphere. It should be noted various Harris-Priester density tables have been constructed to correspond to different levels of activity in the atmosphere.

Results for a full-up Harris-Priester DSST fit to a Harris-Priester Cowell truth model are given in Table 10 (all test procedures for items other than atmospheric drag are identical to the other test procedures described in this section):

Table 10. DSST Harris-Priester DC and Subsequent EG Results I, MACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	H-P AOG SPG F#=150	No	L-S AOG SPG	230.14 sec	16.20 meters (6 its)	21.218 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	H-P AOG SPG F#=150	No	L-S AOG SPG	283.36 sec	2.97 meters (8 its)	4.7777 meters
21x21 J_2^2	Yes	Yes	Yes	Yes	Yes	H-P AOG SPG Solve C_D F#=150	No	L-S AOG SPG	358.83 sec	7.64 meters (11 its)	280.20 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	H-P AOG SPG Solve C_D F#=150	No	L-S AOG SPG	285.00 sec	2.96 meters (8 its)	9.049 meters

As expected, the results in this table show the static Harris-Priester model provides for a tighter DSST fit to a Cowell truth model (stressing the difficulties which arise due to the dynamic, "noisy" nature of the atmosphere; DCs with the Jacchia-Roberts atmospheric model did not provide the same tight closure as with the "smooth" Harris Priester model. Real world analysis of atmospheric effects proves quite challenging due to the noisy and uncertain nature of atmospheric conditions, especially for orbital predictions into the future). Of particular importance in these results is the accuracy improvement gained by modeling resonance in the AOG in cases in which C_D is solved for .

Some testing was also done to try and simulate real-world uncertainties with atmospheric drag. In these tests, a Jacchia-Roberts drag model was used to generate a Cowell truth EG. Then, a Harris-Priester DSST configuration was fit over a three day arc to the Jacchia-Roberts Cowell truth trajectory. Again, a three day predict span followed the fit span, with accuracy metrics derived over both the fit (DC RMS) and predict spans (R&D GTDS Ephemeris Comparison Program). The results of this testing are presented in Table 11:

Table 11. Simulation of Real World Drag Uncertainties, MACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Fit + Predict)
21x21 J_2^2 * * RESON PRD = 1 day	trunc 8 2 11	trunc 8 8 2	No	No	No	H-P AOG F#=275	No	L-S AOG	40.37 sec	764.30 meters (12 its)	15754.0 meters
21x21 J_2^2 * * RESON PRD = 1 day (opt. deck)	trunc 8 2 11	trunc 8 8 2	No	No	No	H-P AOG Solve C_D F#=275	No	L-S AOG	35.04 sec	78.98 meters (7 its)	469.52 meters
21x21 J_2^2 * * RESON PRD = 1 day (opt. deck)	trunc 8 2 11	trunc 8 8 2	No	No	No	H-P AOG Solve C_D F#=150	No	L-S AOG	34.77 sec	80.06 meters (7 its)	636.23 meters

Note the configurations listed in Table 11 are designated as "opt. deck" even though they use the Harris-Priester atmospheric model (the optimal configuration uses the Jacchia-roberts atmospheric model). This designation was given because all geopotential, partial derivative, solve-for, and force model options for the AOG and SPG match the optimal configuration (even though the particular atmospheric model may be different).

The setup for the MACC which provides an optimal balance between accuracy and computational speed can now be given:

- 21x21 geopotential (AOG)
- RESONPRD equal to one day (86400.0 seconds)
- J_2^2 (AOG)
- Truncated zonal short periodic modeling (the maximum power of the eccentricity was set to 2 and the maximum frequency in true longitude was set to 11 in Fourier coefficients for these short periodic expansions)

- Truncated tesseral m-daily short periodic modeling (maximum power of the eccentricity was set to 2 in Fourier Coefficients for these short periodic expansions)
- Jacchia-Roberts drag (AOG)
- Solve C_D
- Lunar / solar third body point mass effects (AOG)
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 1.0 0.0 0.0

Sample input decks for the MACC are given in the appendices.

4.0 High Altitude Circular Case (HACC)

The Explorer 27 (BE-C) orbit was chosen to fulfill the high altitude circular test case. In the ETAS study, the HACC is characterized by a SMAH range of 1000 - 2500 km and an eccentricity range from 0.0 to 0.05. For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a two day arc. A three day DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 60 seconds for the Cowell truth generation (a 45 minute time interval was used in the R&D GTDS Ephemeris Comparison Program).

The osculating elements required for the Cowell truth EG were derived from a five day Cowell fit to an SGP4 ephemeris. The two card element set used to generate the SGP4 ephemeris is given in Table 12:

Table 12. Explorer Two-Card Element Set, HACC, September 1994 SATCAT

Epoch Date YYMMDD HHMMSS.SSSS	940826 074853.5101
Mean Motion	13.37418275 rev/day
Eccentricity	0.0247108
Inclination	41.1904 deg
Longitude of Ascending Node	349.3346 deg
Argument of Perigee	66.5461 deg
Mean Anomaly	296.1065 deg
B*	0.000091 er^{-1}
ORB1 Output Frequency	Every 450.0 Seconds

The specifics for the Cowell DC and subsequent EG are given in Table 13:

Table 13. Cowell DC and Subsequent EG Inputs, HACC

Epoch Date YYMMDD HHMMSS.SSSS	940826 074853.5101
Fit Begin Date YYMMDD HHMMSS.SSSS	940826 074854.0000
Fit End Date YYMMDD HHMMSS.SSSS	940831 074854.0000
EG End Date YYMMDD HHMMSS.SSSS	940903 074854.0000

Table 13. Cowell DC and Subsequent EG Inputs, HACC (Continued)

Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	12th Order Summed Cowell/ Adams Predict-Partially Correct
Step Size	60.0 sec
Gravity Field	21x21 JGM2
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts-Schatten (Solve ρ_1)
Solar Radiation Pressure	Yes (Solve C_R)
Average Spacecraft Cross-Sectional Area	1.0 m^2
Spacecraft Mass	100 kg
Position Standard Deviation	500 meters
Velocity Standard Deviation	50 cm/sec
ORB1 Output Frequency	Every 60.0 Seconds

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in Table 14:

Table 14. DSST DC Specifics, HACC

Epoch Date YYMMDD HHMMSS.SSSS	940826 074853.5101
Fit Span Begin YYMMDD HHMMSS.S	940826 074854.0
Fit Span End YYMMDD HHMMSS.S	940828 074854.0
Semimajor Axis (mean)	7498.0 km
Eccentricity (mean)	0.0247108
Inclination (mean)	41.1904 deg
Longitude of Ascending Node (mean)	349.3346 deg
Argument of Perigee (mean)	66.5461 deg
Mean Anomaly (mean)	296.1065 deg
DSST Input Frame	True of Date
DSST Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)

Table 14. DSST DC Specifics, HACC (Continued)

DSST Step Size	43200.0 sec
Geopotential Model	JGM2
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec
ORB1 Output Frequency	Every 450.0 Seconds

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the HACC are given in Table 15; however, it is first desirable to highlight a few notes concerning the test protocol for the HACC:

- **Total Position RMS is derived over the three day predict span only** (R&D GTDS Ephemeris Comparison Program).
- R&D GTDS default configuration settings are used unless specifically noted.
- RES refers to the inclusion of the 13th and 14th order shallow resonance terms with the AUTOFORC and RESNM keyword cards.
- "trunc" refers to truncated modeling; modeling descriptions corresponding to the R&D GTDS Semianalytic Satellite Theory input processor are specified where needed. Additional details can be found in the R&D GTDS Semianalytic Theory Input Processor keyword description booklet[33].
- All cases which attempt to solve for C_D include first order drag effects in the AOG partials (if C_D is not solved for, then all drag partials in the AOG are shut off). Similarly, all cases which attempt to solve for C_R include solar radiation pressure effects in the AOG partials (if C_R is not solved for, then all solar radiation pressure partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- Most cases have an SSTESTFL card of 1 3; this setting includes all desired AOG partials in the A matrix (J_2 partials are computed analytically; all other partial derivatives are computed via finite differences). In addition, this setting includes desired AOG partial derivatives for non-conservative perturbations in the D matrix via finite differences (these partials were also included in the A matrix). Cases noted by ** have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences (with this setting, third body and J_2^2 AOG partial derivatives, if desired, would not be included anywhere; if they are desired, the SSTESTFL setting of 1 3 should be used).

Table 15. DSST DC and Subsequent EG Results, HACC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	Yes	Yes	Yes	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	1165.3 sec	2.77 meters (11 its)	74.141 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	trunc 6 6 4 2 -10 10	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	203.45 sec	13.93 meters (6 its)	76.522 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	trunc 4 4 4 2 -8 8	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	156.76 sec	20.79 meters (5 its)	71.134 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	144.56 sec	39.88 meters (6 its)	66.637 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	125.23 sec	52.60 meters (6 its)	149.71 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	No	L-S AOG SPG	103.81 sec	58.77 meters (4 its)	332.22 meters

Table 15. DSST DC and Subsequent EG Results, HACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG	L-S AOG SPG	102.21 sec	61.05 meters (4 its)	392.25 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG Solve C_R	L-S AOG SPG	102.64 sec	53.19 meters (4 its)	155.03 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	No	AOG Solve C_R	L-S AOG SPG	98.03 sec	53.38 meters (4 its)	151.55 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	No	AOG Solve C_R	L-S AOG	96.29 sec	53.39 meters (4 its)	151.69 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	Yes	No	No	AOG Solve C_R	L-S AOG	94.58 sec	53.39 meters (4 its)	151.65 meters
8x8 J_2^2	trunc 8 2 11	trunc 8 8 2	No	No	No	No	AOG Solve C_R	L-S AOG	92.89 sec	53.59 meters (4 its)	151.41 meters
6x6 J_2^2	trunc 6 2 11	trunc 6 6 2	No	No	No	No	AOG Solve C_R	L-S AOG	91.18 sec	80.34 meters (4 its)	285.94 meters
8x8 J_2^2 RES	trunc 8 2 11	trunc 8 8 2	No	No	No	No	AOG Solve C_R	L-S AOG	92.39 sec	48.53 meters (4 its)	111.23 meters
21x21 J_2^2 RESON PRD = 1 day	trunc 8 2 11	trunc 8 8 2	No	No	No	No	AOG Solve C_R	L-S AOG	96.83 sec	48.71 meters (4 its)	81.619 meters

Table 15. DSST DC and Subsequent EG Results, HACC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 RESON PRD = 1 day ** 1/5 day step size	trunc 8 2 11	trunc 8 8 2	No	No	No	No	AOG Solve C_R	L-S AOG	97.10 sec	48.71 meters (4 its)	81.693 meters
21x21 J_2^2 RESON PRD = 1 day ** (opt. deck)	trunc 8 2 11	trunc 8 8 2	No	No	No	No	AOG Solve C_R	L-S AOG	93.12 sec	48.71 meters (4 its)	81.619 meters
Space Command's SGP4 (solve for drag term ndot/2)									89.51 sec	415.75 meters (4 its)	1752.9 meters
Space Command's SGP4 (do not solve for drag term ndot/2) $B^* = 0.000091\ er^{-1}$									84.32 sec	422.17 meters (4 its)	694.49 meters

The results in Table 15 indicate the importance of modeling solar radiation pressure in the AOG and solving for C_R (~200 meters over the three day predict). In addition, the impact of higher degree and order zonal and tesseral m-daily terms, as well as shallow tesseral resonance terms, can be clearly seen; specifically, neglecting the contributions from these effects above the 8x8 field (up to the 21x21 gravity model limit used in this testing) more than doubles the predict error. Furthermore, at altitudes characteristic of this orbit, the effects of atmospheric drag and third body short periodics are negligible, while SRP short periodics are on the order of 5 meters. Finally, the tesseral high frequency short periodic, J_2^2 short periodic, and J_2 / m-daily short periodic terms serve to provide accuracy closure with Cowell, but are computationally expensive. For these orbits, their effects can be neglected.

Again, it is of particular **importance** to use extreme care when running an optimized version of the DSST. This particular orbit does experience shallow resonance effects. In the cases where only an 8x8 gravity field (AOG) has been included, the resonant effects were neglected. In order to capture these effects, one DSST case implemented the "RES" modeling (use of the RESNM and AUTOFORC cards with a small base field), while another case implemented a 21x21 geopotential field with a RESONPRD card set equal to one day and geopotential short periodic

terms either removed (as with the tesseral high frequency short periodics) or truncated (as with the zonal and m-daily short periodics). Both of these configurations capture the shallow resonance contributions; however, as was stated in the *MACC* section, the configuration using a 21x21 geopotential model and a RESONPRD card set to one day is (1) simpler than using the AUTOFORC and RESNM configuration and (2) applicable for all cases under the broad scope of the HACC. For these reasons, the 21x21 geopotential model with RESONPRD equal to one day (and geopotential short periodics either removed or truncated) was chosen for the optimal configuration. This configuration was only 5% slower than the more complicated AUTOFORC and RESNM combination, but 30 meters more accurate in the predict span (a benefit gained by the AOG zonal terms above the 8x8 base configuration up to the 21x21 limit). In all, roughly 40 meters is gained in the three day predict with the addition of the shallow resonance terms.

The setup for the HACC which provides an optimal balance between accuracy and computational speed can now be given:

- 21x21 geopotential (AOG)
- RESONPRD equal to one day (86400.0 seconds)
- J_2^2 (AOG)
- Truncated zonal short periodic modeling (the maximum power of the eccentricity was set to 2 and the maximum frequency in true longitude was set to 11 in Fourier coefficients for these short periodic expansions)
- Truncated tesseral m-daily short periodic modeling (maximum power of the eccentricity was set to 2 in Fourier Coefficients for these short periodic expansions)
- Lunar / solar third body point mass effects (AOG)
- Solar Radiation Pressure (AOG)
- Solve for C_R
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 0.0 0.0 1.0

Sample input decks for the HACC are given in the appendices.

5.0 Geosynchronous Case (GEO)

The BS 3A orbit was chosen to fulfill the geosynchronous test case. In the ETAS study, the GEO is characterized by a SMAH range of 33,000 - 39,000 km and an eccentricity range from 0.0 - 0.05. For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a three day arc. A three day DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 450 seconds.

The osculating elements required for the Cowell truth EG were derived from a ten day Cowell fit to an SGP4 ephemeris. The two card element set used to generate the SGP4 ephemeris is given in Table 16:

Table 16. BS 3A Two-Card Element Set, GEO, September 1994 SATCAT

Epoch Date YYMMDD HHMMSS.SSSS	940825 170334.9932
Mean Motion	1.00266891 rev/day
Eccentricity	0.0003102
Inclination	0.0467 deg
Longitude of Ascending Node	243.1923 deg
Argument of Perigee	288.7716 deg

Table 16. BS 3A Two-Card Element Set, GEO, September 1994 SATCAT (Continued)

Mean Anomaly	167.5966 deg
B*	0.0 er^{-1}

The specifics for the Cowell DC and subsequent EG are given in Table 17:

Table 17. Cowell DC and Subsequent EG Inputs, GEO

Epoch Date YYMMDD HHMMSS.SSSS	940825 170334.9932
Fit Begin Date YYMMDD HHMMSS.SSSS	940825 170335.0000
Fit End Date YYMMDD HHMMSS.SSSS	940904 170335.0000
EG End Date YYMMDD HHMMSS.SSSS	940905 170335.0000
Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	12th Order Summed Cowell/ Adams Predict-Partially Correct
Step Size	60.0 sec
Gravity Field	21x21 JGM2
Lunar / Solar Point Masses	Yes
Drag Model	No
Solar Radiation Pressure	Yes (Solve C_R)
Average Spacecraft Cross-Sectional Area	1.0 m^2
Spacecraft Mass	100 kg
Position Standard Deviation	500 meters
Velocity Standard Deviation	50 cm/sec

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in Table 18:

Table 18. DSST DC Specifics, GEO

Epoch Date YYMMDD HHMMSS.SSSS	940825 170334.9932
Fit Span Begin YYMMDD HHMMSS.S	940825 170335.0000
Fit Span End YYMMDD HHMMSS.S	940828 170335.0000
Semimajor Axis (mean)	42167.16
Eccentricity (mean)	0.000275
Inclination (mean)	0.23 deg

Table 18. DSST DC Specifics, GEO (Continued)

Longitude of Ascending Node (mean)	97.6 deg
Argument of Perigee (mean)	75.3 deg
Mean Anomaly (mean)	166.09 deg
DSST Input, Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
DSST Step Size	43200.0 sec
Geopotential Model	JGM2
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the GEO are given in Table 19; first, a few notes concerning the test protocol for the GEO:

- **Total Position RMS is derived over the three day predict span only** (from the R&D GTDS Ephemeris Comparison Program).
- R&D GTDS default configuration settings are used unless specifically noted.
- "NUM SP" refers to numerical short periodics used in conjunction with weak time dependence (WTD) and third body perturbations.
- All cases which attempt to solve for C_R include solar radiation pressure effects in the AOG partials (if C_R is not solved for, then all solar radiation pressure partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- All cases have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences. For these runs, only solar radiation pressure effects (if solving for C_R) have been included in the D matrix.
- Cases with a "*" in the *DC RMS* column had a DC convergence criteria of 1.D-3 (rather than 1.D-4 which was used for all other cases).

Table 19. DSST DC and Subsequent EG Results, GEO

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2	Yes	Yes	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG SPG	137.54 sec	8.24 meters (29 its)	228.17 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG SPG	78.49 sec	8.24 meters (29 its)	228.17 meters
4x4 J_2^2	Yes	Yes	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG SPG	72.01 sec	8.94 meters (30 its)	209.87 meters
4x4 J_2^2	Yes	No	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG SPG	69.32 sec	8.94 meters (29 its)	209.80 meters
4x4 J_2^2 (opt. deck)	Yes	No	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG NUM SP WTD	30.19 sec	5.10 meters (4 its)	21.249 meters
4x4 J_2^2	Yes	No	No	Yes	No	No	AOG Solve C_R	L-S AOG NUM SP WTD	41.91 sec	3.54 meters (12 its)	25.578 meters
4x4 J_2^2	Yes	No	No	Yes	No	No	No	L-S AOG NUM SP WTD	27.80 sec	80.99 meters (3 its) *	391.75 meters
4x4 J_2^2	Yes	No	No	Yes	No	No	AOG SPG Solve C_R	No	35.86 sec	714.81 meters (9 its)	4046.5 meters

Table 19. DSST DC and Subsequent EG Results, GEO (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
4x0 J_2^2	Yes	No	No	Yes	No	No	AOG SPG Solve C_R	L-S AOG NUM SP WTD	46.35 sec	24.74 meters (16 its)	7229.1 meters
Space Command's SGP4 (solve for drag term ndot/2)									59.67 sec	159.50 meters (30 its) *	3934.5 meters
Space Command's SGP4 (do not solve for drag term ndot/2) $B^* = 0.0\ er^{-1}$									36.21 sec	479.85 meters (12 its) *	2060.2 meters

The results in Table 19 indicate a small degree and order geopotential model (i.e., 4x4) can be used without a significant loss in accuracy. In addition, the importance of third body effects and solar radiation pressure (solving for C_R) can clearly be seen. Completely neglecting third body effects leads to ~ 4 km worth of predict error over the three day span; neglecting solar radiation pressure in both the AOG and SPG leads to roughly a 350-400 meter error over the three day predict. Neglecting SRP short periodics (but still modeling SRP in the AOG and solving for C_R), does not significantly impact accuracy (~ 5 m), but causes extra DC iterations for convergence (and, hence, longer run times). Furthermore, weak time dependence, which accounts for the motion of the third bodies over the course of the satellite's orbit in the equations of motion, must be modeled. A weak time independent theory assumes the position of the third body does not move over the course of an averaging interval (the orbital period) in the development of the equations of motion. For low altitude orbits, this assumption works well. However, for geosynchronous orbits (with periods of roughly 24 hours), these results indicate using a weak time independent theory leads to extra DC iterations for convergence and roughly a 200 meter predict error over the course of three days.

The case using a 4x0 geopotential field illustrates the impact of resonance on the geosynchronous orbit. For the three day predict, over 7 km worth of error is introduced by neglecting resonant terms. The impact of using a subset of resonant terms (rather the the full complement for the 1:1 resonance) can clearly be seen in the SGP4 results. The results for optimized DSST indicate the efficiency with which a full complement of resonant terms can be added to a propagation theory.

The setup for the GEO which provides an optimal balance between accuracy and computational speed can now be given:

- 4x4 geopotential (AOG)
- J_2^2 (AOG and SPG)
- Zonal short periodics with default settings
- Lunar / solar third body point mass effects (AOG)
- Numerical third body short periodics (WTD)
- Solar radiation pressure (AOG & SPG)

- Solve for C_R
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 0.0 0.0 1.0

Sample input decks for the GEO are given in the appendices.

6.0 Molniya Case (MOLY)

Satellite #9829 (SATCAT) was chosen to fulfill the Molniya test case[14,20]. In the ETAS study, the Molniya / geostationary transfer orbit is characterized by a SMAH range from 18,000 - 22,000 km and an eccentricity range from 0.05 to 1.0 (this analysis will strictly focus on the Molniya orbit which, typically, has an eccentricity of ~ 0.73).

For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a three day arc. A three day DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 450 seconds.

The osculating elements required for the Cowell truth EG were derived from a six month DSST fit to real data[14]. The six month DSST fit to the real data resulted in a set of mean Keplerian elements which were propagated forward one day to produce the osculating elements used in the Cowell truth EG. The mean Keplerian elements, as well as other settings used in the one day DSST propagation, are listed in Table 20:

Table 20. Mean Element Set Used To Build Osculating Elements, MOLY (from Reference 14)

Epoch Date YYMMDD HHMMSS.SSSS	790803 234212.0000
Semi-Major Axis (mean)	26556.9582 km
Eccentricity (mean)	0.6990986
Inclination (mean)	63.173001 deg
Longitude of Ascending Node (mean)	190.619681 deg
Argument of Perigee (mean)	281.59624 deg
Mean Anomaly (mean)	13.29315 deg
Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	4th Order Runge-Kutta
DSST Step Size	43200.0 sec
Gravity Field	8x8 GEM9
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts $C_D = 2.0$
Solar Radiation Pressure	Yes $C_R = 1.2$

Table 20. Mean Element Set Used To Build Osculating Elements, MOLY (from Reference 14)

Global Short Periodic Select	Moderate Accuracy Molniya Configuration (SPSHPER = 5)
Average Spacecraft Cross-Sectional Area	12.5 m^2
Spacecraft Mass	1250 kg

The specifics for the Cowell truth EG are given in Table 21:

Table 21. Cowell Truth EG Inputs, MOLY

Epoch Date YYMMDD HHMMSS.SSSS	790804 234212.0000
EG End Date YYMMDD HHMMSS.SSSS	790818 234212.0000
Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	Time Regularized Cowell
Time Regularization Constant for Integrator	1.5
Step Size	200 Step Per Revolution
Gravity Field	21x21 GEM10B
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts $C_D = 2.0$
Solar Radiation Pressure	Yes $C_R = 1.2$
Average Spacecraft Cross-Sectional Area	12.5 m^2
Spacecraft Mass	1250 kg

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in Table 22:

Table 22. DSST DC Specifics, MOLY

Epoch Date YYMMDD HHMMSS.SSSS	790804 234212.0000
Fit Span Begin YYMMDD HHMMSS.S	790804 234212.0000
Fit Span End YYMMDD HHMMSS.S	790807 234212.0000
Semimajor Axis (mean)	26572.176 km
Eccentricity (mean)	0.699
Inclination (mean)	63.2 deg
Longitude of Ascending Node (mean)	190.5 deg

Table 22. DSST DC Specifics, MOLY (Continued)

Argument of Perigee (mean)	281.6 deg
Mean Anomaly (mean)	15.429 deg
DSST Input, Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Geopotential Model	GEM10B
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the MOLY are given in Table 23; again, it is first desirable to highlight a few notes concerning the test protocol for the MOLY:

- **Total Position RMS is derived over the three day predict span only** (from R&D GTDS Ephemeris Comparison Program).
- R&D GTDS default configuration settings are used unless specifically noted.
- "trunc" refers to truncated modeling; modeling descriptions corresponding to the R&D GTDS Semianalytic Satellite Theory input processor are specified where needed. Additional details can be found in the R&D GTDS Semianalytic Theory Input Processor keyword description booklet[33].
- "splunara" and "spsolara" also refer to truncated modeling; additional details can be found in the R&D GTDS Semianalytic Theory Input Processor keyword description booklet[33].
- All cases which attempt to solve for C_D include first order drag effects in the AOG partials (if C_D is not solved for, then all drag partials in the AOG are shut off). Similarly, all cases which attempt to solve for C_R include solar radiation pressure effects in the AOG partials (if C_R is not solved for, then all solar radiation pressure partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- Most cases have an SSTESTFL card of 1 3; this setting includes all desired AOG partials in the A matrix (J_2 partials are computed analytically; all other partial derivatives are computed via finite differences). In addition, this setting includes desired AOG partial derivatives for non-conservative perturbations in the D matrix via finite differences (these partials were also included in the A matrix). Cases noted by ** have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences (with this setting, third body and J_2^2 AOG partial derivatives, if desired, would not be included anywhere; if they are desired, the SSTESTFL setting of 1 3 should be used).

Table 23. DSST DC and Subsequent EG Results, MOLY

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2	Yes	Yes	trunc 8 8 33 35 -41 41	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	174.17 sec	20.62 meters (5 its)	149.19 meters
8x8 J_2^2	Yes	Yes	trunc 4 4 33 35 -15 15	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	60.24 sec	33.15 meters (5 its)	146.27 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	43.89 sec	117.30 meters (5 its)	220.10 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG Solve C_R	L-S AOG SPG	39.92 sec	117.65 meters (4 its)	220.08 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG SPG	39.00 sec	117.65 meters (4 its)	220.08 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG	38.49 sec	208.28 meters (4 its)	357.40 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	No	42.90 sec	1027.38 meters (6 its)	12670.0 meters

Table 23. DSST DC and Subsequent EG Results, MOLY (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG splunara 4 4 8 2 spsolara 2 2 4 2	38.83 sec	116.66 meters (4 its)	219.04 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG Solve C_D	No	L-S AOG SPG	38.62 sec	121.09 meters (4 its)	256.95 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	No	AOG Solve C_R	L-S AOG SPG	34.77 sec	117.63 meters (4 its)	218.75 meters
8x8 J_2^2	trunc 6 5 10	trunc 4 4 2	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG SPG	37.24 sec	114.62 meters (4 its)	219.37 meters
8x8 J_2^2	trunc 4 3 8	trunc 4 4 2	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG SPG	36.59 sec	114.82 meters (4 its)	219.33 meters
8x8 J_2^2 * * (opt. deck)	trunc 4 3 8	trunc 4 4 2	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG SPG	34.11 sec	114.82 meters (4 its)	219.33 meters
Space Command's SGP4 (solve for drag term ndot/2)									35.41 sec	2690.67 meters (8 its)	5519.0 meters
Space Command's SGP4 (do not solve for drag term ndot/2) $B^* = 0.0001\ er^{-1}$									28.29 sec	3082.99 meters (4 its)	4537.3 meters

The results in Table 23 demonstrate the wide variety of perturbative effects experienced by Molniya orbits. The low perigee heights contribute to geopotential and atmospheric effects, while the high apogee heights lead to third body and solar radiation pressure effects. Of particular importance are the effects of tesseral resonance (Molniya

orbits usually maintain a repeating groundtrack and complete very nearly two revolutions per day). If neglected, resonance can contribute several kilometers worth of error (as is evident in the analytic DCs, which only model a subset of the resonant terms)[20]. Specifically, the following notes can be taken from Table 23 concerning the short periodic models of DSST:

- drag and solar radiation pressure short periodics do not significantly affect accuracy; they can be truncated to reduce computation time
- neglecting third body short periodics adds ~ 100-150 meters worth of error over the three day predict
- zonal and m-daily short periodics can be truncated to decrease computation time without significantly impacting accuracy
- tesseral high frequency short periodics serve to provide accuracy closure with Cowell (they have an impact on the order of 100 meters), but are computationally expensive

These results also indicate neglecting third body effects (both AOG and SPG) leads to almost 13 km worth of error over the three day predict.

In the first high accuracy DSST run, the DC RMS error is on the order of 20 meters. This error can be attributed to geopotential effects beyond the 8x8 configuration for DSST (up to the 21x21 limit in the Cowell truth model), truncations to the equations of motion in DSST's J_2^2 model (O[e^1] in the AOG and O[e^0] in the SPG), neglecting J_2 / m-daily coupling, an incomplete tesseral high frequency short periodic model at the 8x8 limit (SPTESSLC = 8 8 33 35 -41 41), and an error due to a discrepancy between the truth and DC "solved-for" values of C_D and C_R. If this first high accuracy DSST DC is repeated with the exact values of C_D and C_R used in the truth (C_D = 2.0, C_R = 1.2), a DC RMS of ~ 13 meters results. This implies roughly 7 to 8 meters of the original ~ 20 meter DC RMS error is due to having poor DC solutions for C_D and C_R. Further analysis implementing an 8x8 DSST fit (SPTESSLC = 8 8 33 35 -41 41, J_2 / m-daily off) to an 8x8 Cowell truth model in which both the fit and truth theories used a small value of J_2 (1.0 D^{-6}) and geopotential effects only results in a DC RMS of ~ 3 meters. This 3 meter error can be attributed to the incomplete tesseral high frequency short periodic model of DSST for the 8x8 configuration (remember, the 8x8 DSST configuration isn't really "full-up"; rather, an SPTESSLC of 8 8 33 35 -41 41 was used). If this same test is repeated except for using the regular value of J_2, an error of ~ 7 meters results. This means the truncations in DSST J_2^2 model and the neglect of J_2 / m-daily coupling terms results in ~ 4 meters of error. This leaves an approximate 5 to 6 meter error due to geopotential terms beyond the 8x8 configuration up to the 21x21 limit used in the truth. As a final note, it should be mentioned this specific breakdown of errors is dependent upon the geometry of this particular orbit, the relationship between the fit span and perigee locations, etc. Therefore, these error quantifications should be used as a "rule of thumb" metrics.

The setup for the MOLY which provides an optimal balance between accuracy and computational speed can now be given:

- 8x8 geopotential (AOG)
- J_2^2 (AOG and SPG)
- Truncated central body zonal harmonic short periodics (SPZONALS = 4 3 8)
- Truncated m-daily tesseral harmonic short periodics (SPMDAILY = 4 4 2)
- Lunar / solar third body point mass effects (AOG & SPG)
- Atmospheric drag (AOG)
- Solve for C_D
- Solar radiation pressure (AOG)
- Solve for C_R
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 1.0 0.0 1.0

Sample input decks for the MOLY are given in the appendices.

7.0 Near Earth Eccentric Case (NEEC)

The Vanguard 2 orbit was chosen to fulfill the near earth eccentric test case. In the ETAS study, the NEEC is characterized by a SMAH range from 0 - 2500 km and an eccentricity range from 0.05 to 1.0. For this test case, multiple runs were made in which varying configurations of DSST were fit to a Cowell truth model over a three day arc. A three day DSST EG with the DC solve-for parameters followed the fit span. Accuracy metrics were derived from comparisons between the DSST and Cowell trajectories over both the fit (DC RMS) and predict spans (from the R&D GTDS Ephemeris Comparison Program). ORB1 output was produced every 450 seconds.

The osculating elements required for the Cowell truth EG were derived from a five day Cowell fit to an SGP4 ephemeris. The two card element set used to generate the SGP4 ephemeris is given in Table 24:

Table 24. Vanguard 2 Two-Card Element Set, NEEC, September 1994 SATCAT

Epoch Date YYMMDD HHMMSS.SSSS	940826 073513.6735
Mean Motion	11.73921485 rev/day
Eccentricity	0.1522640
Inclination	32.8834 deg
Longitude of Ascending Node	251.8592 deg
Argument of Perigee	10.8368 deg
Mean Anomaly	352.1515 deg
B*	0.000154 er^{-1}

The specifics for the Cowell DC and subsequent EG are given in Table 25:

Table 25. Cowell DC and Subsequent EG Inputs, NEEC

Epoch Date YYMMDD HHMMSS.SSSS	940826 073513.6735
Fit Begin Date YYMMDD HHMMSS.SSSS	940826 073514.0000
Fit End Date YYMMDD HHMMSS.SSSS	940831 073514.0000
EG End Date YYMMDD HHMMSS.SSSS	940905 073514.0000
Input, Integration, and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Integrator	12th Order Summed Cowell/ Adams Predict-Partially Correct
Step Size	60.0 sec
Gravity Field	21x21 JGM2
Lunar / Solar Point Masses	Yes
Drag Model	Jacchia-Roberts-Schatten (Solve ρ_1)

Table 25. Cowell DC and Subsequent EG Inputs, NEEC (Continued)

Solar Radiation Pressure	Yes (Solve C_R)
Average Spacecraft Cross-Sectional Area	1.0 m^2
Spacecraft Mass	100 kg
Position Standard Deviation	500 meters
Velocity Standard Deviation	50 cm/sec

The same initial guess of the state vector and observation noise standard deviation were used for all of the DSST DC runs. These values are highlighted in Table 26:

Table 26. DSST DC Specifics, NEEC

Epoch Date YYMMDD HHMMSS.SSSS	940826 073513.6735
Fit Span Begin YYMMDD HHMMSS.S	940826 073514.0
Fit Span End YYMMDD HHMMSS.S	940829 073514.0
Semimajor Axis (mean)	8177.913 km
Eccentricity (mean)	0.1522640
Inclination (mean)	32.8834 deg
Longitude of Ascending Node (mean)	251.8592 deg
Argument of Perigee (mean)	10.8368 deg
Mean Anomaly (mean)	352.1515 deg
DSST Input Frame	True of Date
DSST Integration and Output Frame	Earth Equator and Equinox of 1950 (Mean of 1950)
Geopotential Model	JGM2
Position Standard Deviation	100 meters
Velocity Standard Deviation	10 cm/sec

In the DSST DC runs, varying configurations corresponding to different perturbation modeling were used to determine the optimal balance of accuracy and computational speed. Results of the DC's and subsequent EG's for the NEEC are given in Table 27; however, it is first desirable to highlight a few notes concerning the test protocol for the NEEC:

- **Total Position RMS is derived over the three day predict span only** (from R&D GTDS Ephemeris Comparison Program).
- R&D GTDS default configuration settings are used unless specifically noted.
- "trunc" refers to truncated modeling; modeling descriptions corresponding to the R&D GTDS Semianalytic Satellite Theory input processor are specified where needed. Additional details can be found in the R&D GTDS Semianalytic Theory Input Processor keyword description booklet[33].

- RES refers to the inclusion of the 11th and 12th order shallow resonance terms with the AUTOFORC and RESNM keyword cards.
- All cases which attempt to solve for C_D include first order drag effects in the AOG partials (if C_D is not solved for, then all drag partials in the AOG are shut off). Similarly, all cases which attempt to solve for C_R include solar radiation pressure effects in the AOG partials (if C_R is not solved for, then all solar radiation pressure partials in the AOG are shut off). All cases include J_2 partials analytically in the AOG. No other AOG or SPG partials were included in any of the runs.
- Most cases have an SSTESTFL card of 1 3; this setting includes all desired AOG partials in the A matrix (J_2 partials are computed analytically; all other partial derivatives are computed via finite differences). In addition, this setting includes desired AOG partial derivatives for non-conservative perturbations in the D matrix via finite differences (these partials were also included in the A matrix). Cases noted by ** have an SSTESTFL card of 1 2; this setting puts only J_2 AOG partials into the A matrix (computed analytically). All other desired AOG partials for non-conservative perturbations are included in the D matrix via finite differences (with this setting, third body and J_2^2 AOG partial derivatives, if desired, would not be included anywhere; if they are desired, the SSTESTFL setting of 1 3 should be used).

Table 27. DSST DC and Subsequent EG Results, NEEC

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2/ m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	trunc 21 21 21 15 -37 37	Yes	Yes	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	541.29 sec	41.76 meters (6 its)	223.16 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	trunc 6 6 21 15 -27 27	Yes	Yes	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	202.46 sec	42.76 meters (9 its)	234.47 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	trunc 6 6 21 15 -27 27	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	132.27 sec	42.83 meters (8 its)	232.69 meters
21x21 J_2^2 RESON PRD = 1 day	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	70.74 sec	55.08 meters (9 its)	239.42 meters

Table 27. DSST DC and Subsequent EG Results, NEEC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
12x12 J_2^2 RESON PRD = 1 day	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	57.42 sec	55.37 meters (9 its)	456.24 meters
8x8 J_2^2	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	48.50 sec	58.63 meters (8 its)	389.63 meters
8x8 J_2^2 RES	Yes	Yes	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	47.46 sec	61.08 meters (6 its)	207.29 meters
21x21 J_2^2 RESON PRD = 1 day	Trunc. 8 7 17	Trunc. 8 8 6	No	Yes	No	J-R AOG SPG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	47.67 sec	61.06 meters (6 its)	229.95 meters
21x21 J_2^2 RESON PRD = 1 day	Trunc. 8 7 17	Trunc. 8 8 6	No	Yes	No	J-R AOG Solve C_D	AOG SPG Solve C_R	L-S AOG SPG	45.92 sec	61.06 meters (6 its)	229.95 meters
21x21 J_2^2 RESON PRD = 1 day	Trunc. 8 7 17	Trunc. 8 8 6	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG SPG	45.54 sec	61.06 meters (6 its)	229.94 meters
21x21 J_2^2 RESON PRD = 1 day	Trunc. 8 7 17	Trunc. 8 8 6	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG	44.10 sec	60.94 meters (6 its)	228.52 meters

Table 27. DSST DC and Subsequent EG Results, NEEC (Continued)

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
21x21 J_2^2 RESON PRD = 1 day	Trunc. 6 5 13	Trunc. 6 6 4	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG	42.63 sec	69.54 meters (6 its)	217.87 meters
21x21 J_2^2 RESON PRD = 1 day	Trunc. 4 3 9	Trunc. 4 4 2	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG	46.30 sec	78.95 meters (8 its)	238.46 meters
21x21 J_2^2 * * RESON PRD = 1 day (opt. deck)	Trunc. 6 5 13	Trunc. 6 6 4	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	L-S AOG	37.89 sec	69.42 meters (6 its)	218.71 meters
21x21 J_2^2 * * RESON PRD = 1 day	Trunc. 6 5 13	Trunc. 6 6 4	No	Yes	No	No	AOG Solve C_R	L-S AOG	35.97 sec	78.48 meters (6 its)	312.51 meters
21x21 J_2^2 * * RESON PRD = 1 day	Trunc. 6 5 13	Trunc. 6 6 4	No	Yes	No	J-R AOG Solve C_D	No	L-S AOG	36.75 sec	67.82 meters (6 its)	267.96 meters
21x21 J_2^2 * * RESON PRD = 1 day	Trunc. 6 5 13	Trunc. 6 6 4	No	Yes	No	J-R AOG Solve C_D	AOG Solve C_R	No	38.06 sec	72.15 meters (6 its)	266.27 meters

Table 27. **DSST DC and Subsequent EG Results, NEEC (Continued)**

GRAV (AOG)	Zonal SP	M-daily SP	TESS SP	J_2^2 SP	J_2 / m-daily SP	Drag	SRP	3rd Body	Run Time	DC RMS	Total Position RMS (Predict Span)
Space Command's SGP4 (solve for drag term ndot/2)									28.27 sec	909.86 meters (5 its)	1080.7 meters
Space Command's SGP4 (do not solve for drag term ndot/2) $B^* = 0.000154\ er^{-1}$									26.69 sec	910.34 meters (4 its)	3284.2 meters

The results in Table 27 indicate the importance of modeling shallow resonance terms; adding the 11th and 12th order shallow resonance terms reduces the predict error by roughly 200 meters. The short periodic models for drag, SRP, and third body have negligible accuracy contributions, but each add a few seconds of run time; therefore, these short periodic models can be neglected to reduce computation time. Like many other cases, the tesseral high frequency short periodic and J_2 / m-daily short periodic terms serve to provide closure with Cowell, but are computationally expensive. For these orbits, their effects can be neglected.

These results also highlight the contribution of several of the AOG terms:

- not modeling drag in the AOG (as well as not solving for C_D) adds roughly 100 meters worth of predict error
- not modeling solar radiation pressure in the AOG (as well as not solving for C_R) adds roughly 50 meters worth of predict error
- not modeling third body effects in the AOG adds roughly 50 meters worth of predict error

In the first high accuracy DSST run, the DC RMS error is on the order of 40 meters. This error can mainly be attributed to truncations to the equations of motion in DSST's J_2^2 model ($O[e^1]$ in the AOG and $O[e^0]$ in the SPG), an incomplete tesseral high frequency short periodic model, and discrepancies between the truth and DC "solved-for" values of C_D and C_R. If this same DSST case is fit to another Cowell truth model containing 21x21 geopotential effects only, the DC RMS is reduced to ~ 21 meters (in other words, ~ 20 meters can be attributed to the poor DC solution for C_D and C_R). If this test is taken one step further such that both the 21x21 Cowell truth and DSST use a small value of J_2 (1.0 D^{-6}), the error is reduced to ~ 1.7 meters (i.e., errors due to truncations in DSST's J_2^2 model are on the order of ~ 20 meters). This means ~1-2 meters of error can be attributed to not having a complete 21x21 tesseral high frequency short periodic model (remember, an SPTESSLC of 21 21 21 15 -37 37 was used). Finally, it should be mentioned this specific breakdown of errors is dependent upon the geometry of this particular orbit, the relationship between the fit span and perigee locations, etc. Therefore, these error quantifications should be used as a "rule of thumb" metrics.

Again, it is of particular **importance** to use extreme care when running an optimized version of the DSST. Note how the optimized deck for this case implements a 21x21 geopotential field with a RESONPRD card set to one day and truncated short periodics (rather than the RESNM and AUTOFORC combination). Again, some accuracy and run-time is sacrificed for a deck which is (1) simpler to implement than the RESNM and AUTOFORC combination and (2) general enough to capture resonant terms which might be experienced by other satellites under the broad definition of the NEEC.

The setup for the NEEC which provides an optimal balance between accuracy and computational speed can now be given:

- 21x21 geopotential (AOG)
- RESONPRD equal to one day (86400.0 seconds)
- J_2^2 (AOG and SPG)
- Truncated zonal short periodics (SPZONALS = 6 5 13)
- Truncated m-daily short periodics (SPMDAILY = 6 6 4)
- Lunar / solar third body point mass effects (AOG)
- Atmospheric drag (AOG)
- Solve for C_D
- Solar radiation pressure (AOG)
- Solve for C_R
- SSTESTFL 1 2 0 0.0
- SSTAPGFL 1 0 0 1.0 0.0 1.0

Sample input decks for the NEEC are given in the appendices.

8.0 Conclusions

This paper describes R&D GTDS input decks which provide a balance between speed and accuracy when using the DSST orbit propagation theory. The orbit classes studied in this effort are similar to those investigated in the Ephemeris Theory Accuracy Study (ETAS) performed by Kaman Sciences[5], and include low, medium, and high altitude circular orbits, as well as Molniya, geosynchronous, and near earth eccentric orbits. In addition to the optimized decks (refer to Appendix A), standardized test cases have been supplied for each of the orbit types analyzed herein (refer to Appendix B). All results were obtained from batch differential correction fits and subsequent ephemeris comparisons to Cowell generated truth data. The input decks specified in this study provide the R&D GTDS user with insight concerning the accuracy and computational expense of the various force model options (AOG & SPG) available in DSST for each orbital class. The optimal decks also provide the basis for an automatic force model option which can be added to current DSST implementations.

9.0 Recommendations

Clearly, this paper does not address all of the orbit types currently in use. Therefore, if optimal DSST input decks are desired for other orbit types, further research is required. In addition, software modifications should be made to R&D GTDS to allow the user to automatically implement these optimal input decks (if so desired). These setups could be specified on the SPSHPER keyword card. Finally, an automatic resonance selection capability (based on the input semimajor axis) should be considered for R&D GTDS.

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Appendix A

Optimized DSST Input Decks

LACC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                    SATNAME    1234567
EPOCH                 820224.0              0.0
ELEMENT1  1  6  1     6628.457              0.0089              64.84
ELEMENT2              224.51                271.89              115.16
OBSINPUT 15           820224000000.0        820224013000.0
ORBTYPE   5  1  1     43200.0               1.0
DMOPT
OBSDEV   21 22 23     100.                  100.                100.
OBSDEV   24 25 26     10.                   10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1     1.D-4
END
OGOPT
NCBODY    1
DRAG      1           1.0
ATMOSDEN        1
SCPARAM               1.D-6                 100.D0
SPGRVFRC  1  1  1     3.0                   1.0                 3.0
SPTESSLC  6  6  4     2.0                   -10.0               10.0
POTFIELD  1  6
MAXDEGEQ  1           8.
MAXORDEQ  1           8.
STATEPAR  3
STATETAB  1  2  3     4.0                   5.0                 6.0
DRAGPAR   1
DRAGPAR2  1  1
SSTESTFL  1  2  0     0.0
SSTAPGFL  1  0  0     1.0                   6.0                 0.0
END
FIN
CONTROL   EPHEM                             OUTPUT              SATNAME    1234567
OUTPUT    1  2  1     820224.               030000.0            86400.0
ORBTYPE   5  1  1     43200.0               1.0
OGOPT
NCBODY    1
DRAGPAR   0
DRAG      1           1.0
ATMOSDEN        1
SCPARAM               1.D-6                 100.D0
SPGRVFRC  1  1  1     3.0                   1.0                 3.0
SPTESSLC  6  6  4     2.0                   -10.0               10.0
POTFIELD  1  6
MAXDEGEQ  1           8.
MAXORDEQ  1           8.
OUTOPT   21           820224000000.0        820224030000.0      450.0
END
FIN
```

MACC OPTIMIZED INPUT DECK

```
CONTROL    DC                                                          LNDSAT-4    8207201
EPOCH                       820224.0             0.0
ELEMENT1  3   6   1         7077.8               0.0011                98.2
ELEMENT2                    158.1                89.4                  176.0
OBSINPUT 15                 820224000000.0       820227000000.0
ORBTYPE   5   1   1         43200.0              1.0
DMOPT
OBSDEV   21  22  23         100.                 100.                  100.
OBSDEV   24  25  26         10.                  10.                   10.
END
DCOPT
PRINTOUT  1       4
CONVERG  30       1         1.D-4
END
OGOPT
DRAG      1                 1
ATMOSDEN          1
SPDRAG    0
SCPARAM                     1.D-6                100.D0
SPGRVFRC  1   1   3         3.0                  3.0                   3.0
SPZONALS  8   2  11
SPMDAILY  8   8   2
POTFIELD  1   6
MAXDEGEQ  1                 21.
MAXORDEQ  1                 21.
RESONPRD                    86400.0
STATEPAR  3
STATETAB  1   2   3         4.0                  5.0                   6.0
DRAGPAR   1
DRAGPAR2  1   1
SSTESTFL  1   2
SSTAPGFL  1   0   0         1.0                  0.0                   0.0
END
FIN
CONTROL    EPHEM                                 OUTPUT                LNDSAT-4    8207201
OUTPUT    1   2   1         820302.              0.0                   86400.0
ORBTYPE.  5   1   1         43200.0              1.0
OGOPT
DRAG      1                 1
DRAGPAR   0
ATMOSDEN          1
SPDRAG    0
SCPARAM                     1.D-6                100.D0
SPGRVFRC  1   1   3         3.0                  3.0                   3.0
SPZONALS  8   2  11
SPMDAILY  8   8   2
POTFIELD  1   6
MAXDEGEQ  1                 21.
MAXORDEQ  1                 21.
RESONPRD                    86400.0
OUTOPT   21                 820224000000.0       820302000000.0        450.0
END
FIN
```

HACC OPTIMIZED INPUT DECK

```
CONTROL    DC                                                         EXPLORER    65032A
EPOCH                  940826.0               074853.5101
ELEMENT1   3   6   1   7498.0                 0.0247108               41.1904
ELEMENT2               349.3346               66.5461                 296.1065
OBSINPUT 15            940826074854.0         940828074854.0
ORBTYPE    5   1   1   43200.0                1.0
DMOPT
OBSDEV     21 22 23    100.                   100.                    100.
OBSDEV     24 25 26    10.                    10.                     10.
END
DCOPT
PRINTOUT   1       4
CONVERG    30      1   1.D-4
END
OGOPT
SOLRAD     1           1.0
SPSRP      0
SCPARAM                1.D-6                  100.D0
SPGRVFRC   1   1   3   3.0                    3.0                     3.0
SPZONALS   8   2  11
SPMDAILY   8   8   2
POTFIELD   1   2
MAXDEGEQ   1           21.
MAXORDEQ   1           21.
RESONPRD               86400.0
STATEPAR   3
STATETAB   1   2   3   4.0                    5.0                     6.0
SOLRDPAR   1
SSTESTFL   1   2   0   0.0
SSTAPGFL   1   0   0   0.0                    0.0                     1.0
END
FIN
CONTROL    EPHEM                              OUTPUT                  EXPLORER    65032A
OUTPUT     1   2   1   940831.                074854.0                86400.0
ORBTYPE    5   1   1   43200.0                1.0
OGOPT
SOLRAD     1           1.0
SPSRP      0
SCPARAM                1.D-6                  100.D0
SOLRDPAR   0
SPGRVFRC   1   1   3   3.0                    3.0                     3.0
SPZONALS   8   2  11
SPMDAILY   8   8   2
POTFIELD   1   2
MAXDEGEQ   1           21.
MAXORDEQ   1           21.
RESONPRD               86400.0
OUTOPT     21          940826074854.0         940831074854.0          450.0
END
FIN
```

GEOSYNCHRONOUS OPTIMIZED INPUT DECK

```
CONTROL   DC                                                       BS3A          20771
EPOCH                 940825.0            170334.9932
ELEMENT1  1  6  1     42167.16            0.000275                 0.23
ELEMENT2              97.6                75.3                     166.09
OBSINPUT 15           940825170335.0      940828170335.0
ORBTYPE   5  1  1     43200.0             1.0
DMOPT
OBSDEV   21 22 23     100.                100.                     100.
OBSDEV   24 25 26     10.                 10.                      10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1     1.D-4
END
OGOPT
SOLRAD    1           1.0
SCPARAM               1.D-6               100.D0
SPGRVFRC  1  3  3     2.0                 1.0                      3.0
SPNUMGRV  7  1  8     2.0                 2.0                      3600.0
POTFIELD  1  2
MAXDEGEQ  1           4.
MAXORDEQ  1           4.
STATEPAR  3
STATETAB  1  2  3     4.0                 5.0                      6.0
SOLRDPAR  1
SSTESTFL  1  2  0     0.0
SSTAPGFL  1  0  0     0.0                 0.0                      1.0
END
FIN
CONTROL   EPHEM                             OUTPUT                 BS3A          20771
OUTPUT    1  2  1     940905.             170335.0                 86400.0
ORBTYPE   5  1  1     43200.0             1.0
OGOPT
SOLRAD    1           1.0
SOLRDPAR  0
SCPARAM               1.D-6               100.D0
SPGRVFRC  1  3  3     2.0                 1.0                      3.0
SPNUMGRV  7  1  8     2.0                 2.0                      3600.0
POTFIELD  1  2
MAXDEGEQ  1           4.
MAXORDEQ  1           4.
OUTOPT   21           940825170335.0      940905170335.0           450.0
END
FIN
```

MOLNIYA OPTIMIZED INPUT DECK

```
CONTROL   DATAMGT                                                NSSC        9829
OGOPT
POTFIELD  1  6
END
FIN
CONTROL   DC                                                     NSSC        9829
EPOCH                  790804.0            234212.0
ELEMENT1  1  6  1      26572.176           0.699                 63.2
ELEMENT2               190.5               281.6                 15.429
OBSINPUT 15            790804234212.0      790807234212.0
ORBTYPE   5  1  1      43200.0             1.0
DMOPT
OBSDEV   21 22 23      100.                100.                  100.
OBSDEV   24 25 26      10.                 10.                   10.
END
OGOPT
DRAG      1            1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM                12.5D-6             1250.D0
SOLRAD    1            1.0
SPSRP     0
SPGRVFRC  1  1  3      1.                  1.                    3.
SPZONALS  4  3  8
SPMDAILY  4  4  2
MAXDEGEQ  1            8.
MAXORDEQ  1            8.
STATEPAR  3
STATETAB  1  2  3      4.0                 5.0                   6.0
DRAGPAR   1
DRAGPAR2  1  1
SOLRDPAR  1
SSTESTFL  1  2  0      0.0
SSTAPGFL  1  0  0      1.0                 0.0                   1.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1      1.D-3
END
FIN
CONTROL   EPHEM                            OUTPUT                NSSC        9829
OUTPUT    1  2  1      790818.0            234212.0              172800.0
ORBTYPE   5  1  1      43200.0             1.0
OGOPT
DRAGPAR   0
DRAG      1            1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM                12.5D-6             1250.D0
SOLRAD    1            1.0
SPSRP     0
SOLRDPAR  0
SPGRVFRC  1  1  3      1.                  1.                    3.
SPZONALS  4  3  8
SPMDAILY  4  4  2
MAXDEGEQ  1            8.
MAXORDEQ  1            8.
OUTOPT   21            790804234212.0      790818234212.0        450.
END
FIN
```

NEEC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                   VANGARD2     59001A
EPOCH                   940826.0              073513.6735
ELEMENT1  3   6   1     8177.913              0.1522640          32.8834
ELEMENT2                251.8592              10.8368            352.1515
OBSINPUT 15             940826073514.0        940829073514.0
ORBTYPE   5   1   1     43200.0               1.0
DMOPT
OBSDEV   21 22 23       100.                  100.               100.
OBSDEV   24 25 26       10.                   10.                10.
END
DCOPT
PRINTOUT  1       4
CONVERG  30       1     1.D-4
END
OGOPT
DRAG      1             1.0
ATMOSDEN          1
SPDRAG    0
SCPARAM                 1.D-6                 100.D0
SOLRAD    1             1.0
SPSRP     0
SPGRVFRC  1   1   3     3.0                   1.0                3.0
SPZONALS  6   5  13
SPMDAILY  6   6   4
POTFIELD  1   2
MAXDEGEQ  1             21.
MAXORDEQ  1             21.
RESONPRD                86400.0
STATEPAR  3
STATETAB  1   2   3     4.0                   5.0                6.0
DRAGPAR   1
DRAGPAR2  1   1
SOLRDPAR  1
SSTESTFL  1   2   0     0.0
SSTAPGFL  1   0   0     1.0                   0.0                1.0
END
FIN
CONTROL   EPHEM                               OUTPUT             VANGARD2     59001A
OUTPUT    1   2   1     940905.               073514.0           86400.0
ORBTYPE   5   1   1     43200.0               1.0
OGOPT
DRAGPAR   0
DRAG      1             1.0
ATMOSDEN          1
SPDRAG    0
SCPARAM                 1.D-6                 100.D0
SOLRAD    1             1.0
SPSRP     0
SOLRDPAR  0
SPGRVFRC  1   1   3     3.0                   1.0                3.0
SPZONALS  6   5  13
SPMDAILY  6   6   4
POTFIELD  1   2
MAXDEGEQ  1             21.
MAXORDEQ  1             21.
RESONPRD                86400.0
OUTOPT   21             940826073514.0        940905073514.0     450.0
END
FIN
```

Appendix B

Optimal Deck Test Case Summaries

This appendix details information required to reproduce results for each of the optimal DSST input deck test cases described in this document. Specifically, the following information is given:

- The input decks required to generate the Cowell truth orbit. For cases starting with a two card elements set, SGP4 ephemeris generation decks are given, along with the Cowell DC and subsequent Cowell ephemeris generation decks that were used to fit the SGP4 ephemeris and produce the truth trajectory. For cases starting with DSST mean Keplerian elements, the DSST ephemeris generation decks used to convert the mean elements to osculating elements are given, along with the Cowell ephemeris generation decks which used the osculating elements as inputs to produce a truth trajectory. In all cases, output summaries are included to verify the reproduction of truth data.

- The optimal DSST DC input decks. Vital statistics from the DC output report are included to verify reproduction of the test cases. GTDS input decks and output summaries are also given for the comparison of the predicted "optimal" ephemerides to the truth data.

LACC Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with mean Keplerian elements
2) Propagate forward one day using DSST to obtain osculating elements
3) Propagate osculating elements forward using Cowell theory to generate truth data

```
CONTROL   EPHEM                              SATNAME   1234567
EPOCH              820223.0       0.0
ELEMENT1  3  6  1  6635.0814      0.010201164    64.9567
ELEMENT2           228.6393       271.2229       88.164558
OUTPUT    1  2  1  820224.0       0.0            43200.0
ORBTYPE   5  1  1  43200.0        1.0
OGOPT
SPSHPER   3
DRAG      1        1.0
ATMOSDEN        1
SCPARAM            1.D-6          100.D0
POTFIELD  1  6
MAXDEGEQ  1        8.
MAXORDEQ  1        8.
END
FIN
CONTROL   EPHEM                   OUTPUT         SATNAME   1234567
OUTPUT    1  2  1  820302.0       0.0            86400.0
ORBTYPE   2  1  1  60.0
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SCPARAM            1.D-6          100.D0
POTFIELD  1  6
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
OUTOPT    1        820224000000.0 820302000000.0 450.0
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

GTDS FINAL REPORT

PAGE 26

SATELLITE NAME	SATNAME			
SATELLITE NUMBER	1234567			
RUN REFERENCE DATE	FEB 23, 1982	0 HRS	0 MINS	0.00000 SECONDS
RUN EPOCH DATE	FEB 24, 1982	0 HRS	0 MINS	0.00000 SECONDS
RUN FINAL TIME	FEB 27, 1982	8 HRS	30 MINS	0.00000 SECONDS
TOTAL TIME OF FLIGHT	3 DAYS	8 HRS	30 MINS	0.00000 SECONDS
CAUSE OF TERMINATION	IMPACT ON CENTRAL BODY			

END CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	0.5593199869577529E+04	Y	0.3044772358638768E+04	Z	0.7984863339607982E+03
VX	-0.1067207195712157E+01	VY	0.2984383598904645E+01	VZ	-0.6524063462834691E+01
SMA	0.5566864380626048E+04	ECC	0.1592293732194910E+00	INC	0.6460801957824047E+02
LAN	0.2119745942735612E+03	AP	0.3382687050241062E+03	MA	0.1987370536808272E+03
EA	0.1961928616234382E+03	P	0.1148218242491020E+01	SLR	0.5425722138440627E+04
PR	0.4680456054501052E+04	APR	0.6453272706751044E+04	PH	-0.1697681945498948E+04
APH	0.7513470675104418E+02	C3	-0.3580116316352344E+02	TA	0.1938156243439430E+03
RA	0.2856256354454737E+02	DEC	0.7146771499993070E+01	VPA	0.9257533557949978E+02
AZ	0.1543948811906195E+03	RMAG	0.6418107503189311E+04	VMAG	0.7253197965800011E+01

INITIAL CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	-0.3260654138207152E+04	Y	-0.5065846974834642E+04	Z	0.2825154370949725E+04
VX	0.4586987250728033E+01	VY	0.4241328473629827E+00	VZ	0.6200975003201267E+01
SMA	0.6628457212322488E+04	ECC	0.8922785978361727E-02	INC	0.6483789425043533E+02
LAN	0.2245064324605057E+03	AP	0.2718922445048535E+03	MA	0.1151619800839504E+03
EA	0.1156229426311188E+03	P	0.1491856897264069E+01	SLR	0.6627929480346489E+04
PR	0.6569312907250206E+04	APR	0.6687601517394770E+04	PH	0.1911749072502062E+03
APH	0.3094635173947700E+03	C3	-0.3006736162217285E+02	TA	0.1160830242166191E+03
RA	0.2372324679669332E+03	DEC	0.2512393544617055E+02	VPA	0.8953902904810165E+02
AZ	0.2800897356458445E+02	RMAG	0.6654033979560448E+04	VMAG	0.7724793311207796E+01

*** SECTIONING SUMMARY ***

NUMBER OF SECTIONS SCHEDULED = 1
NUMBER OF SECTIONS COMPLETED = 1

SECTION	CENTRAL BODY	TIME OF CROSSING				TIME INTO FLIGHT			CAUSE OF CROSSING
			H	M	S	H	M	S	
1	EARTH	FEB 27	8	30	0.000	80	30	0.000	IMPACT ON CENTRAL BODY

*** FILE GENERATION SUMMARY ***

AN ORB-1 FILE HAS BEEN GENERATED
START TIME OF THE FILE = 820224000000.000
END TIME OF THE FILE = 820227083000.000

*** NUMBER OF GTDS ERRORS ENCOUNTERED= 0**

LACC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                    SATNAME    1234567
EPOCH                820224.0            0.0
ELEMENT1  1  6  1    6628.457            0.0089              64.84
ELEMENT2             224.51              271.89              115.16
OBSINPUT 15          820224000000.0      820224013000.0
ORBTYPE   5  1  1    43200.0             1.0
DMOPT
OBSDEV   21 22 23    100.                100.                100.
OBSDEV   24 25 26    10.                 10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1    1.D-4
END
OGOPT
NCBODY    1
DRAG      1          1.0
ATMOSDEN        1
SCPARAM              1.D-6               100.D0
SPGRVFRC  1  1  1    3.0                 1.0                 3.0
SPTESSLC  6  6  4    2.0                 -10.0               10.0
POTFIELD  1  6
MAXDEGEQ  1          8.
MAXORDEQ  1          8.
STATEPAR  3
STATETAB  1  2  3    4.0                 5.0                 6.0
DRAGPAR   1
DRAGPAR2  1  1
SSTESTFL  1  2  0    0.0
SSTAPGFL  1  0  0    1.0                 6.0                 0.0
END
FIN
CONTROL   EPHEM                           OUTPUT              SATNAME    1234567
OUTPUT    1  2  1    820224.              030000.0            86400.0
ORBTYPE   5  1  1    43200.0             1.0
OGOPT
NCBODY    1
DRAGPAR   0
DRAG      1          1.0
ATMOSDEN        1
SCPARAM              1.D-6               100.D0
SPGRVFRC  1  1  1    3.0                 1.0                 3.0
SPTESSLC  6  6  4    2.0                 -10.0               10.0
POTFIELD  1  6
MAXDEGEQ  1          8.
MAXORDEQ  1          8.
OUTOPT   21          820224000000.0      820224030000.0      450.0
END
FIN
```

SUMMARY OF LACC OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 6

```
                                       ************************************************
                                       *  POSITION ERROR RMS (M)    17.404205        *
SATELLITE       SATNAME   1234567      *  CURRENT WEIGHTED RMS      0.11590288       *   START TIME   820224   0.000
                                       *  PREDICTED WEIGHTED RMS    0.11590311       *
EPOCH           820224      0.000      *  PREVIOUS WEIGHTED RMS     0.11590339       *   END TIME     820224   12230.000
                                       *  SMALLEST WEIGHTED RMS     0.11590339       *
COORD. SYSTEM   MEAN OF 1950.0         *  RELATIVE CHANGE IN RMS    4.40389818E-06   *   NO. OBS. AVAILABLE     72
                                       *  PENALTY                   0.00000000       *
CENTRAL BODY    EARTH                  *  DC HAS CONVERGED                           *   NO. OBS. INCLUDED      72
                                       *                                             *
                                       ************************************************   NO. OBS. ACCEPTED 72 100 PCT.
```

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	12	12	12	12	12	12
NO. ACCEPTED	12 (100%)	12 (100%)	12 (100%)	12 (100%)	12 (100%)	12 (100%)
WEIGHTED RMS	7.0606E-02	0.1319	8.8872E-02	0.1270	0.1428	0.1152
MEAN RESDUAL	0.5897	-0.1745	1.190	-0.4787	0.7263	0.2646
STANDARD DEV	7.036	13.19	8.807	1.176	1.229	1.122

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	0	6	6	0	6	6	0	6	6
NO. ACCEPTED	0 (0%)	6 (100%)	6 (100%)	0 (0%)	6 (100%)	6 (100%)	0 (0%)	6 (100%)	6 (100%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	0	6	6	0	6	6	0	6	6
NO. ACCEPTED	0 (0%)	6 (100%)	6 (100%)	0 (0%)	6 (100%)	6 (100%)	0 (0%)	6 (100%)	6 (100%)

THERE ARE 7 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 7

A	H	K	P	Q	LAM	CSUBD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

COMPARE DECK FOR LACC:

```
CONTROL   COMPARE                                          SATNAME    1234567
COMPOPT
CMPEPHEM  1102102  820224013000.0        820224030000.0        7.5
END
FIN
```

LACC COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 13

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	820224	24500.000	8.498042E-04	820224	21500.000	2.135948E-02
CROSS TRACK	820224	21500.000	1.065784E-02	820224	15230.000	4.588219E-02
ALONG TRACK	820224	13000.000	5.055184E-03	820224	30000.000	1.013102E-01
TOTAL	820224	13000.000	1.904066E-02	820224	30000.000	1.052537E-01

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	820224	22230.000	1.024987E-05	820224	30000.000	1.508931E-04
CROSS TRACK	820224	24500.000	3.131833E-06	820224	13730.000	5.871673E-05
ALONG TRACK	820224	24500.000	1.064040E-07	820224	13730.000	2.326795E-05
TOTAL	820224	20730.000	4.330394E-05	820224	30000.000	1.585244E-04

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	1.2699E-02	7.2032E-05
CROSS TRACK	3.0955E-02	3.6669E-05
ALONG TRACK	5.6565E-02	1.3224E-05
TOTAL	6.5720E-02	8.1903E-05

1 GTDS COMPARE PROGRAM PAGE 6

0

NORMAL COMPLETION OF JOB

MACC Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with mean Keplerian elements
2) Propagate forward one day using DSST to obtain osculating elements
3) Propagate osculating elements forward using Cowell theory to generate truth data

```
CONTROL   EPHEM                                                LNDSAT-4   8207201
EPOCH                  820223.0            0.0
ELEMENT1  3  6  1      7077.787            0.011542            98.250452
ELEMENT2               158.15349           89.4                312.90205
OUTPUT    1  2  1      820224.0            0.0                 43200.0
ORBTYPE   5  1  1      43200.0             1.0
OGOPT
MAXDEGEQ  1            8
MAXORDEQ  1            8
DRAG      1            2
SCPARAM                1.D-6               100.D0
POTFIELD  1  6
END
FIN
CONTROL   EPHEM                            OUTPUT              LNDSAT-4   8207201
OUTPUT    1  2  1      820302.0            0.0                 86400.0
ORBTYPE   2  1  1      60.0
OGOPT
DRAG      1            1
ATMOSDEN        1
MAXDEGEQ  1            21.0
MAXORDEQ  1            21.0
OUTOPT    1            820224000000.0      820302000000.0      450.0
SCPARAM                1.D-6               100.D0
POTFIELD  1  6
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

GTDS FINAL REPORT

PAGE 26

SATELLITE NAME	LNDSAT-4			
SATELLITE NUMBER	8207201			
RUN REFERENCE DATE	FEB 23, 1982	0 HRS	0 MINS	0.00000 SECONDS
RUN EPOCH DATE	FEB 24, 1982	0 HRS	0 MINS	0.00000 SECONDS
RUN FINAL TIME	MAR 2, 1982	0 HRS	0 MINS	0.00000 SECONDS
TOTAL TIME OF FLIGHT	6 DAYS	0 HRS	0 MINS	0.00000 SECONDS
CAUSE OF TERMINATION	SPECIFIED TIME OF FLIGHT REACHED			

END CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	-0.6324740968942853E+04	Y	0.2072818657994322E+04	Z	0.2268217443679385E+04
VX	0.2709923724289485E+01	VY	0.3235086740423296E+00	VZ	0.7047377494503171E+01
SMA	0.7084998645530947E+04	ECC	0.1181967691217463E-01	INC	0.9829175379969750E+02
LAN	0.1647012051719553E+03	AP	0.6995308761596635E+02	MA	0.3101176171932150E+03
EA	0.3095957802717889E+03	P	0.1648610790422618E+01	SLR	0.7084008837479219E+04
PR	0.7001256250617576E+04	APR	0.7168741040444318E+04	PH	0.6231182506175765E+03
APH	0.7906030404443181E+03	C3	-0.2812988822880213E+02	TA	0.3090719555792481E+03
RA	0.1618543854217003E+03	DEC	0.1881864707692896E+02	VPA	0.9052185894543646E+02
AZ	0.3512363878729003E+03	RMAG	0.7031623986318168E+04	VMAG	0.7557372162575918E+01

INITIAL CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	0.2434985999885991E+04	Y	-0.1956779793707955E+04	Z	-0.6439371344275231E+04
VX	-0.6438412655705597E+01	VY	0.2019610450187177E+01	VZ	-0.3080855896509433E+01
SMA	0.7072044035079919E+04	ECC	0.1265314835977568E-01	INC	0.9831861805268920E+02
LAN	0.1587564854292450E+03	AP	0.8334407619753735E+02	MA	0.1616125399350340E+03
EA	0.1618385110459561E+03	P	0.1644091238755010E+01	SLR	0.7070911785530140E+04
PR	0.6982560412697187E+04	APR	0.7161527657462651E+04	PH	0.6044224126971867E+03
APH	0.7833896574626515E+03	C3	-0.2818141671791043E+02	TA	0.1620631405221004E+03
RA	0.3212142831384352E+03	DEC	-0.6412151715921503E+02	VPA	0.8977401196957886E+02
AZ	0.1993584452782684E+03	RMAG	0.7157069741883023E+04	VMAG	0.7417793266916529E+01

*** SECTIONING SUMMARY ***

NUMBER OF SECTIONS SCHEDULED = 1
NUMBER OF SECTIONS COMPLETED = 1

SECTION	CENTRAL BODY	TIME OF CROSSING		H	M	S	TIME INTO FLIGHT H	M	S	CAUSE OF CROSSING
1	EARTH	MAR	2	0	0	0.000	144	0	0.000	SPECIFIED TIME OF FLIGHT REACHED

*** FILE GENERATION SUMMARY ***

AN ORB-1 FILE HAS BEEN GENERATED
START TIME OF THE FILE = 820224000000.000
END TIME OF THE FILE = 820302000000.000

*** NUMBER OF GTDS ERRORS ENCOUNTERED= 0**

MACC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                      LNDSAT-4   8207201
EPOCH                  820224.0         0.0
ELEMENT1  3  6  1      7077.8           0.0011             98.2
ELEMENT2               158.1            89.4               176.0
OBSINPUT 15            820224000000.0   820227000000.0
ORBTYPE   5  1  1      43200.0          1.0
DMOPT
OBSDEV    21 22 23     100.             100.               100.
OBSDEV    24 25 26     10.              10.                10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1      1.D-4
END
OGOPT
DRAG      1            1
ATMOSDEN        1
SPDRAG    0
SCPARAM                1.D-6            100.D0
SPGRVFRC  1  1  3      3.0              3.0                3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  6
MAXDEGEQ  1            21.
MAXORDEQ  1            21.
RESONPRD               86400.0
STATEPAR  3
STATETAB  1  2  3      4.0              5.0                6.0
DRAGPAR   1
DRAGPAR2  1  1
SSTESTFL  1  2
SSTAPGFL  1  0  0      1.0              0.0                0.0
END
FIN
CONTROL   EPHEM                         OUTPUT             LNDSAT-4   8207201
OUTPUT    1  2  1      820302.          0.0                86400.0
ORBTYPE   5  1  1      43200.0          1.0
OGOPT
DRAG      1            1
DRAGPAR   0
ATMOSDEN        1
SPDRAG    0
SCPARAM                1.D-6            100.D0
SPGRVFRC  1  1  3      3.0              3.0                3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  6
MAXDEGEQ  1            21.
MAXORDEQ  1            21.
RESONPRD               86400.0
OUTOPT   21            820224000000.0   820302000000.0     450.0
END
FIN
```

SUMMARY OF MACC OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 7

```
                                         ************************************************
                                         *   POSITION ERROR RMS (M)      76.510799       *
SATELLITE        LNDSAT-4  8207201       *   CURRENT WEIGHTED RMS        0.45418732      *   START TIME  820224 0.000
                                         *   PREDICTED WEIGHTED RMS      0.45580603      *
EPOCH            820224       0.000      *   PREVIOUS WEIGHTED RMS       0.45582550      *   END TIME    820226 235230.000
                                         *   SMALLEST WEIGHTED RMS       0.45582550      *
COORD. SYSTEM    MEAN OF 1950.0          *   RELATIVE CHANGE IN RMS      3.59387939E-03  *   NO. OBS. AVAILABLE  3456
                                         *   PENALTY                     0.00000000      *
CENTRAL BODY     EARTH                   *   DC HAS CONVERGED                            *   NO. OBS. INCLUDED   3456
                                         *                                               *
                                         ************************************************   NO. OBS. ACCEPTED 3423 99 PCT
```

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	576	576	576	576	576	576
NO. ACCEPTED	570 (98%)	576 (100%)	575 (99%)	560 (97%)	575 (99%)	567 (98%)
WEIGHTED RMS	0.4544	0.3822	0.4861	0.4854	0.3506	0.5407
MEAN RESDUAL	0.3981	0.2098	0.4400	9.6646E-02	-3.4598E-02	-3.1819E-02
STANDARD DEV	45.44	38.22	48.61	4.853	3.506	5.407

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	156	168	198	234	204	168	156	192	228
NO. ACCEPTED	156 (100%)	167 (99%)	197 (99%)	234 (100%)	204 (100%)	166 (98%)	153 (98%)	191 (99%)	225 (98%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	240	204	174	168	174	216	228	192	156
NO. ACCEPTED	237 (98%)	202 (99%)	172 (98%)	165 (98%)	171 (98%)	213 (98%)	225 (98%)	190 (98%)	155 (99%)

THERE ARE 7 SOLVE PARAMETERS

```
NUMBER OF DYNAMIC SOLVE PARAMETERS =  7
A            H            K            P            Q            LAM          CSUBD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR =  0

NUMBER OF BIASES BEING SOLVED FOR =  0
```

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE =   0 *

COMPARE DECK FOR MACC:

```
CONTROL   COMPARE                                            LNDSAT-4   8207201
COMPOPT
CMPEPHEM  1102102  820227000000.0        820302000000.0       45.
END
FIN
```

MACC COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 97

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	820228	94500.000	1.374394E-03	820227	184500.000	9.115588E-02
CROSS TRACK	820301	141500.000	5.420682E-04	820301	21500.000	8.921743E-02
ALONG TRACK	820227	163000.000	2.999669E-03	820301	193000.000	3.680619E-01
TOTAL	820227	163000.000	1.286429E-02	820301	193000.000	3.764689E-01

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	820228	81500.000	5.361974E-06	820301	124500.000	3.909677E-04
CROSS TRACK	820228	21500.000	5.331724E-07	820227	43000.000	1.131149E-04
ALONG TRACK	820228	163000.000	3.636120E-08	820228	73000.000	9.822645E-05
TOTAL	820227	133000.000	2.279860E-05	820301	124500.000	3.942775E-04

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	4.0244E-02	2.0643E-04
CROSS TRACK	3.2424E-02	3.3844E-05
ALONG TRACK	1.8994E-01	4.4235E-05
TOTAL	1.9685E-01	2.1381E-04

1 GTDS COMPARE PROGRAM PAGE 7

0

NORMAL COMPLETION OF JOB

HACC Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with 2-card element set
2) Propagate 2-card element set forward using SGP4 to obtain SGP4-based ephemeris
3) Fit Cowell theory to SGP4-based ephemeris
4) Propagate Cowell DC solve-for vector forward to produce truth data

```
CONTROL   EPHEM                                               EXPLORER     65032A
EPOCH                 940826.0              074853.5101
ELEMENT1  8 18  1  13.37418275              0.0247108           41.1904
ELEMENT2              349.3346              66.5461             296.1065
ELEMENT3              -0.00000029           0.000000            0.000091
OUTPUT    1  2  1  940831.0                 074854.0            86400.0
ORBTYPE  14  1  8  1.0
OGOPT
POTFIELD  1  7
OUTOPT    1           940826074854.0        940831074854.0      450.0
END
FIN
```

SGP4 EPHEMERIS OUTPUT SUMMARY:

```
                                        GTDS FINAL REPORT
PAGE 12

                        SATELLITE NAME              EXPLORER
                        SATELLITE NUMBER                65032
                        RUN REFERENCE DATE          AUG  26, 1994     0 HRS      0 MINS       0.00000 SECONDS
                        RUN EPOCH DATE              AUG  26, 1994     7 HRS     48 MINS      53.51010 SECONDS
                        RUN FINAL TIME              AUG  31, 1994     7 HRS     48 MINS      54.00000 SECONDS
                        TOTAL TIME OF FLIGHT                5 DAYS    0 HRS      0 MINS       0.48990 SECONDS
                        CAUSE OF TERMINATION        SPECIFIED TIME OF FLIGHT REACHED

                                        ***END  CONDITIONS***
   CENTRAL BODY IS EARTH    (INERTIAL SYSTEM)                          MEAN OF 1950.0 -- EARTH EQUATOR
   X     0.4887549306874350E+04       Y     -0.5498692794044931E+04            Z    -0.1768913280088411E+04
   VX    0.4786071196055583E+01       VY     0.3047635044022132E+01            VZ    0.4475570612493452E+01

   SMA   0.7501908902328932E+04       ECC    0.2499062301383419E-01            INC   0.4120299091118378E+02
   LAN   0.3279770705618683E+03       AP     0.9098909633714638E+02            MA    0.2511718748703972E+03
   EA    0.2498278467174672E+03       P      0.1796246619168853E+01            SLR   0.7497223725870149E+04
   PR    0.7314431525066702E+04       APR    0.7689386279591161E+04            PH    0.9362965250667021E+03
   APH   0.1311251279591161E+04       C3    -0.2656662492104218E+02            TA    0.2484894377614734E+03

   RA    0.3122485301361856E+03       DEC   -0.1335140772811090E+02            VPA   0.9134420137012032E+02
   AZ    0.5064941371860270E+02       RMAG   0.7566558982575450E+04            VMAG  0.7226706663664657E+01

                                        ***INITIAL  CONDITIONS***
   CENTRAL BODY IS EARTH    (INERTIAL SYSTEM)                          "NORAD" TRUE OF REF. -- EARTH EQUATOR
   X     0.7294468899368215E+04       Y     -0.1366234653003144E+04            Z     0.6456847303414492E+01
   VX    0.8537442543527309E+00       VY     0.5478661153568532E+01            VZ    0.4850032676429656E+01

   SMA   0.7499106169847256E+04       ECC    0.2471080000000148E-01            INC   0.4119040000000000E+02
   LAN   0.3493346000000000E+03       AP     0.6654609999999940E+02            MA    0.2961065000000007E+03
   EA    0.2948214689775155E+03       P      0.1795240089651203E+01            SLR   0.7494527038366274E+04
   PR    0.7313797257105383E+04       APR    0.7684415082589128E+04            PH    0.9356622571053831E+03
   APH   0.1306280082589128E+04       C3    -0.2657655399004164E+02            TA    0.2935295945886971E+03

   RA    0.3493915621046252E+03       DEC    0.4984967616062881E-01            VPA   0.9128520794121377E+02
   AZ    0.4880962477968625E+02       RMAG   0.7421314933473303E+04            VMAG  0.7366642671522530E+01

                                        *** SECTIONING SUMMARY ***
                        NUMBER OF SECTIONS SCHEDULED =      1
                        NUMBER OF SECTIONS COMPLETED =      1
SECTION CENTRAL BODY    TIME OF CROSSING                   TIME INTO FLIGHT         CAUSE OF CROSSING
                                       H   M     S            H    M     S
   1        EARTH        AUG  31       7  48   54.000       120    0    0.490       SPECIFIED TIME OF FLIGHT REACHED

                                        *** FILE GENERATION SUMMARY ***

                        AN ORB-1 FILE HAS BEEN GENERATED
                        START TIME OF THE FILE =    940826074854.000
                        END   TIME OF THE FILE =    940831074854.000


                                   *** NUMBER OF GTDS ERRORS ENCOUNTERED=     0**
```

TRUTH DATA GENERATION

COWELL DC & EPHEM DECK (FIT TO SGP4-BASED EPHEMERIS) TO GENERATE TRUTH DATA:

```
                                                                EXPLORER    65032A
CONTROL   DC
EPOCH                  940826.0          074853.5101
ELEMENT1  1  2  1  7502.98           0.02566            41.2
ELEMENT2               349.0             65.1               297.22
OBSINPUT 15            940826074854.0    940831074854.0
ORBTYPE   2  1  1  60.0
DMOPT
OBSDEV   21 22 23  500.0             500.0              500.0
OBSDEV   24 25 26  50.0              50.0               50.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1  1.D-3
END
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SCPARAM            1.D-6             100.D0
SOLRAD    1        1.0
POTFIELD  1  2
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
STATEPAR  1
STATETAB  1  2  3  4.0               5.0                6.0
DRAGPAR   1
SOLRDPAR  1
END
FIN
CONTROL   EPHEM                      OUTPUT             EXPLORER    65032A
OUTPUT    1  2  1  940903.0          074854.0           86400.0
ORBTYPE   2  1  1  60.0
OGOPT
DRAG      1        1.0
DRAGPAR   0
ATMOSDEN        1
SCPARAM            1.D-6             100.D0
SOLRAD    1        1.0
SOLRDPAR  0
POTFIELD  1  2
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
OUTOPT   22  2  1  940826074854.0    940903074854.0
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

ITERATION NUMBER 5

```
                                        ***********************************************
                                        *  POSITION ERROR RMS (M)     428.11032      *
SATELLITE       EXPLORER    65032       *  CURRENT WEIGHTED RMS       0.45208753     *   START TIME  940826  75624.000
                                        *  PREDICTED WEIGHTED RMS     0.45480147     *
EPOCH           940826  74853.510       *  PREVIOUS WEIGHTED RMS      0.45491167     *   END TIME     940831  74854.000
                                        *  SMALLEST WEIGHTED RMS      0.45491167     *
COORD. SYSTEM   MEAN OF 1950.0          *  RELATIVE CHANGE IN RMS     6.20810804E-03 *   NO. OBS. AVAILABLE  5760
                                        *  PENALTY                    0.00000000     *
CENTRAL BODY    EARTH                   *  DC HAS CONVERGED                          *   NO. OBS. INCLUDED   5760
                                        *                                            *
                                        ***********************************************   NO. OBS. ACCEPTED 5732 99 PCT
```

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	960	960	960	960	960	960
NO. ACCEPTED	949 (98%)	948 (98%)	955 (99%)	960 (100%)	960 (100%)	960 (100%)
WEIGHTED RMS	0.5014	0.4876	0.4891	0.4272	0.3988	0.3968
MEAN RESDUAL	-69.59	-129.6	144.0	-2.610	0.4184	2.070
STANDARD DEV	240.9	206.5	197.7	21.20	19.94	19.73

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	306	306	318	336	318	324	318	318	342
NO. ACCEPTED	306 (100%)	306 (100%)	318 (100%)	336 (100%)	318 (100%)	321 (99%)	317 (99%)	315 (99%)	342 (100%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	336	330	324	318	306	312	336	306	306
NO. ACCEPTED	332 (98%)	327 (99%)	320 (98%)	317 (99%)	304 (99%)	308 (98%)	334 (99%)	305 (99%)	306 (100%)

THERE ARE 8 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 8

X   Y   Z   VX   VY   VZ   RHO1   SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 5 *

HACC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                    EXPLORER    65032A
EPOCH                 940826.0            074853.5101
ELEMENT1  3  6  1     7498.0              0.0247108             41.1904
ELEMENT2              349.3346            66.5461               296.1065
OBSINPUT 15           940826074854.0      940828074854.0
ORBTYPE   5  1  1     43200.0             1.0
DMOPT
OBSDEV    21 22 23    100.                100.                  100.
OBSDEV    24 25 26    10.                 10.                   10.
END
DCOPT
PRINTOUT  1     4
CONVERG   30    1     1.D-4
END
OGOPT
SOLRAD    1           1.0
SPSRP     0
SCPARAM               1.D-6               100.D0
SPGRVFRC  1  1  3     3.0                 3.0                   3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  2
MAXDEGEQ  1           21.
MAXORDEQ  1           21.
RESONPRD              86400.0
STATEPAR  3
STATETAB  1  2  3     4.0                 5.0                   6.0
SOLRDPAR  1
SSTESTFL  1  2  0     0.0
SSTAPGFL  1  0  0     0.0                 0.0                   1.0
END
FIN
CONTROL   EPHEM                           OUTPUT                EXPLORER    65032A
OUTPUT    1  2  1     940831.             074854.0              86400.0
ORBTYPE   5  1  1     43200.0             1.0
OGOPT
SOLRAD    1           1.0
SPSRP     0
SCPARAM               1.D-6               100.D0
SOLRDPAR  0
SPGRVFRC  1  1  3     3.0                 3.0                   3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  2
MAXDEGEQ  1           21.
MAXORDEQ  1           21.
RESONPRD              86400.0
OUTOPT    21          940826074854.0      940831074854.0        450.0
END
FIN
```

SUMMARY OF HACC OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 4

SATELLITE	EXPLORER 65032	POSITION ERROR RMS (M)	48.705827	START TIME 940826 74954.000
		CURRENT WEIGHTED RMS	0.28884820	
EPOCH	940826 74853.510	PREDICTED WEIGHTED RMS	0.30075942	END TIME 940828 74854.000
		PREVIOUS WEIGHTED RMS	0.30075980	
COORD. SYSTEM	MEAN OF 1950.0	SMALLEST WEIGHTED RMS	0.30075980	NO. OBS. AVAILABLE ****
		RELATIVE CHANGE IN RMS	3.96050355E-02	
CENTRAL BODY	EARTH	PENALTY	0.00000000	NO. OBS. INCLUDED ****
		DC HAS CONVERGED		NO. OBS. ACCEPTED **** 99 PCT

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	2880	2880	2880	2880	2880	2880
NO. ACCEPTED	2851 (98%)	2878 (99%)	2880 (100%)	2815 (97%)	2861 (99%)	2880 (100%)
WEIGHTED RMS	0.2873	0.3243	0.2218	0.2951	0.3432	0.2431
MEAN RESDUAL	0.6894	0.3899	0.4194	8.5625E-02	-4.9562E-02	-6.2918E-02
STANDARD DEV	28.72	32.42	22.18	2.950	3.432	2.430

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	864	954	948	1014	972	972	972	972	1026
NO. ACCEPTED	864 (100%)	954 (100%)	942 (99%)	1005 (99%)	954 (98%)	963 (99%)	972 (100%)	972 (100%)	1026 (100%)
0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	1026	948	948	924	888	942	1002	936	972
NO. ACCEPTED	1026 (100%)	938 (98%)	938 (98%)	918 (99%)	883 (99%)	931 (98%)	987 (98%)	922 (98%)	970 (99%)

THERE ARE 7 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 7

A H K P Q LAM SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

COMPARE DECK FOR HACC:

```
CONTROL   COMPARE                                              EXPLORER    65032A
COMPOPT
CMPEPHEM  1102102  940828074854.0      940831074854.0      45.
END
FIN
```

HACC COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 97

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	940829	181854.000	1.677306E-03	940831	23354.000	7.173356E-02
CROSS TRACK	940828	220354.000	1.377805E-04	940831	40354.000	5.726527E-02
ALONG TRACK	940828	211854.000	3.657224E-05	940830	134854.000	2.025899E-01
TOTAL	940828	220354.000	4.484148E-03	940830	134854.000	2.033114E-01

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	940828	190354.000	2.955573E-07	940830	121854.000	1.702762E-04
CROSS TRACK	940831	23354.000	2.772951E-08	940831	74854.000	4.844473E-05
ALONG TRACK	940828	91854.000	6.024580E-08	940830	181854.000	6.031790E-05
TOTAL	940828	211854.000	1.714331E-05	940830	121854.000	1.734637E-04

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	2.8012E-02	7.0302E-05
CROSS TRACK	2.6375E-02	2.5504E-05
ALONG TRACK	7.1981E-02	2.8725E-05
TOTAL	8.1619E-02	8.0112E-05

1 GTDS COMPARE PROGRAM PAGE 7

0

NORMAL COMPLETION OF JOB

GEO Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with 2-card element set
2) Propagate 2-card element set forward using SGP4 to obtain SGP4-based ephemeris
3) Fit Cowell theory to SGP4-based ephemeris
4) Propagate Cowell DC solve-for vector forward to produce truth data

```
                                                                BS3A          20771
CONTROL    EPHEM
EPOCH                940825.0               170334.9932
ELEMENT1   8 18  1   1.00266891             0.0003102             0.0467
ELEMENT2             243.1923               288.7716              167.5966
ELEMENT3             0.00000000             0.000000              0.00000
OUTPUT     1  2  1   940905.0               170335.0              86400.0
ORBTYPE   14  1  8   1.0
OGOPT
POTFIELD   1  7
OUTOPT     1         940825170335.0         940905170335.0        450.0
END
FIN
```

SGP4 EPHEMERIS OUTPUT SUMMARY:

```
                                   GTDS FINAL REPORT

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                   SATELLITE NAME            BS3A
                   SATELLITE NUMBER             20771
                   RUN REFERENCE DATE        AUG  25, 1994     0 HRS     0 MINS      0.00000 SECONDS
                   RUN EPOCH DATE            AUG  25, 1994    17 HRS     3 MINS     34.99320 SECONDS
                   RUN FINAL TIME            SEPT  5, 1994    17 HRS     3 MINS     35.00000 SECONDS
                   TOTAL TIME OF FLIGHT            11 DAYS     0 HRS     0 MINS      0.00680 SECONDS
                   CAUSE OF TERMINATION      SPECIFIED TIME OF FLIGHT REACHED

                                     ***END  CONDITIONS***
CENTRAL BODY IS EARTH   (INERTIAL SYSTEM)                      MEAN OF 1950.0 -- EARTH EQUATOR
X     0.4147498563686865E+05      Y    -0.7679518537839341E+04          Z    -0.1767766902439355E+03
VX    0.5596246403209475E+00      VY    0.3022273313587103E+01          VZ   -0.3373151171135438E-02

SMA   0.4216876442281726E+05      ECC   0.2746131686644057E-03          INC   0.2109068722704865E-01
LAN   0.1874391381048706E+03      AP    0.3449220111341053E+03          MA    0.1777193918337379E+03
EA    0.1777200177816512E+03      P     0.2393837128664726E+02          SLR   0.4216876124276986E+05
PR    0.4215718432480045E+05      APR   0.4218034452083408E+05          PH    0.3577904932480045E+05
APH   0.3580220952083408E+05      C3   -0.4726256572321093E+01          TA    0.1777206436437087E+03

RA    0.3500817939879975E+03      DEC   0.6291991122203051E-02          VPA   0.8999937405206303E+02
AZ    0.9002013027414259E+02      RMAG  0.4218033535351635E+05          VMAG  0.3073650453186145E+01

                                     ***INITIAL  CONDITIONS***
CENTRAL BODY IS EARTH   (INERTIAL SYSTEM)                      "NORAD" TRUE OF REF. -- EARTH EQUATOR
X     0.3952629838700647E+05      Y    -0.1472472717593263E+05          Z     0.3416690188895451E+02
VX    0.1073172496565432E+01      VY    0.2880181807058570E+01          VZ   -0.2780373401265742E-03

SMA   0.4216716110762471E+05      ECC   0.3101999999597714E-03          INC   0.4670000000000000E-01
LAN   0.2431922999999999E+03      AP    0.2887715999999954E+03          MA    0.1675966000000055E+03
EA    0.1676004163972050E+03      P     0.2393700604426692E+02          SLR   0.4216715705013011E+05
PR    0.4215408085425082E+05      APR   0.4218024136099860E+05          PH    0.3577594585425081E+05
APH   0.3580210636099859E+05      C3   -0.4726436278015460E+01          TA    0.1676042322164656E+03

RA    0.3395681343168720E+03      DEC   0.4641115339300120E-01          VPA   0.8999618360262247E+02
AZ    0.9000518602416244E+02      RMAG  0.4217993624890280E+05          VMAG  0.3073621077231286E+01

                                  *** SECTIONING SUMMARY ***
                   NUMBER OF SECTIONS SCHEDULED =     1
                   NUMBER OF SECTIONS COMPLETED =     1
SECTION CENTRAL BODY   TIME OF CROSSING                TIME INTO FLIGHT      CAUSE OF CROSSING
                                  H   M    S             H    M     S
  1        EARTH       SEPT  5    17   3   35.000       264   0    0.007     SPECIFIED TIME OF FLIGHT REACHED

                                *** FILE GENERATION SUMMARY ***

                   AN ORB-1 FILE HAS BEEN GENERATED
                   START TIME OF THE FILE =     940825170335.000
                   END   TIME OF THE FILE =     940905170335.000


                         *** NUMBER OF GTDS ERRORS ENCOUNTERED=      0**
```

TRUTH DATA GENERATION

COWELL DC & EPHEM DECK (FIT TO SGP4-BASED EPHEMERIS) TO GENERATE TRUTH DATA:

```
CONTROL    DC                                                    BS3A          20771
EPOCH                 940825.0              170334.9932
ELEMENT1   1  2  1    42167.16              0.000275             0.23
ELEMENT2              97.6                  75.3                 166.09
OBSINPUT 15           940825170335.0        940904170335.0
ORBTYPE    2  1  1    60.0
DMOPT
OBSDEV     21 22 23   500.0                 500.0                500.0
OBSDEV     24 25 26   50.0                  50.0                 50.0
END
DCOPT
PRINTOUT   1     4
CONVERG    30    1    1.D-3
END
OGOPT
SOLRAD     1          1.0
SCPARAM               1.D-6                 100.D0
POTFIELD   1  2
MAXDEGEQ   1          21.0
MAXORDEQ   1          21.0
STATEPAR   1
STATETAB   1  2  3    4.0                   5.0                  6.0
SOLRDPAR   1
END
FIN
CONTROL    EPHEM                            OUTPUT               BS3A          20771
OUTPUT     1  2  1    940905.0              170335.0             86400.0
ORBTYPE    2  1  1    60.0
OGOPT
SOLRAD     1          1.0
SCPARAM               1.D-6                 100.D0
SOLRDPAR   0
POTFIELD   1  2
MAXDEGEQ   1          21.0
MAXORDEQ   1          21.0
OUTOPT     21         940825170335.0        940905170335.0       450.0
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

ITERATION NUMBER 3

SATELLITE	BS3A 20771	POSITION ERROR RMS (M)	2453.3437	
		CURRENT WEIGHTED RMS	1.9976620	START TIME 940825 171105.000
		PREDICTED WEIGHTED RMS	2.5423798	
EPOCH	940825 170334.993	PREVIOUS WEIGHTED RMS	2.5424042	END TIME 940904 170335.000
		SMALLEST WEIGHTED RMS	2.5424042	
COORD. SYSTEM	MEAN OF 1950.0	RELATIVE CHANGE IN RMS	0.21426264	NO. OBS. AVAILABLE ****
		PENALTY	0.00000000	
CENTRAL BODY	EARTH	DC HAS CONVERGED		NO. OBS. INCLUDED ****
				NO. OBS. ACCEPTED **** 97 PCT

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	1920	1920	1920	1920	1920	1920
NO. ACCEPTED	1876 (97%)	1920 (100%)	1698 (88%)	1920 (100%)	1920 (100%)	1920 (100%)
WEIGHTED RMS	2.180	2.191	3.943	0.1615	0.1515	0.3833
MEAN RESDUAL	-113.6	-2.593	-102.3	0.1289	-0.1550	-0.1233
STANDARD DEV	1084.	1095.	1969.	8.075	7.574	19.17

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	690	684	684	678	672	660	630	594	564
NO. ACCEPTED	690 (100%)	682 (99%)	670 (97%)	649 (95%)	633 (94%)	621 (94%)	599 (95%)	594 (100%)	564 (100%)
0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	582	588	612	612	630	636	648	672	684
NO. ACCEPTED	582 (100%)	584 (99%)	602 (98%)	596 (97%)	602 (95%)	607 (95%)	629 (97%)	666 (99%)	684 (100%)

THERE ARE 7 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 7
X Y Z VX VY VZ SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

GEOSYNCHRONOUS OPTIMIZED INPUT DECK

```
CONTROL   DC                                                    BS3A        20771
EPOCH                 940825.0              170334.9932
ELEMENT1  1  6  1     42167.16              0.000275            0.23
ELEMENT2              97.6                  75.3                166.09
OBSINPUT 15           940825170335.0        940828170335.0
ORBTYPE   5  1  1     43200.0               1.0
DMOPT
OBSDEV    21 22 23    100.                  100.                100.
OBSDEV    24 25 26    10.                   10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG   30    1     1.D-4
END
OGOPT
SOLRAD    1           1.0
SCPARAM               1.D-6                 100.D0
SPGRVFRC  1  3  3     2.0                   1.0                 3.0
SPNUMGRV  7  1  8     2.0                   2.0                 3600.0
POTFIELD  1  2
MAXDEGEQ  1           4.
MAXORDEQ  1           4.
STATEPAR  3
STATETAB  1  2  3     4.0                   5.0                 6.0
SOLRDPAR  1
SSTESTFL  1  2  0     0.0
SSTAPGFL  1  0  0     0.0                   0.0                 1.0
END
FIN
CONTROL   EPHEM                             OUTPUT              BS3A        20771
OUTPUT    1  2  1     940905.               170335.0            86400.0
ORBTYPE   5  1  1     43200.0               1.0
OGOPT
SOLRAD    1           1.0
SOLRDPAR  0
SCPARAM               1.D-6                 100.D0
SPGRVFRC  1  3  3     2.0                   1.0                 3.0
SPNUMGRV  7  1  8     2.0                   2.0                 3600.0
POTFIELD  1  2
MAXDEGEQ  1           4.
MAXORDEQ  1           4.
OUTOPT    21          940825170335.0        940905170335.0      450.0
END
FIN
```

SUMMARY OF GEOSYNCHRONOUS OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 4

SATELLITE	BS3A 20771	POSITION ERROR RMS (M)	5.1035665	START TIME 940825 171105.000
		CURRENT WEIGHTED RMS	2.20243188E-02	
		PREDICTED WEIGHTED RMS	2.20766417E-02	
EPOCH	940825 170334.993	PREVIOUS WEIGHTED RMS	2.20767451E-02	END TIME 940828 170335.000
		SMALLEST WEIGHTED RMS	2.20767451E-02	
COORD. SYSTEM	MEAN OF 1950.0	RELATIVE CHANGE IN RMS	2.37472948E-03	NO. OBS. AVAILABLE 3456
		PENALTY	0.00000000	
CENTRAL BODY	EARTH	DC HAS CONVERGED		NO. OBS. INCLUDED 3456
				NO. OBS. ACCEPTED 3454 99 PCT

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	576	576	576	576	576	576
NO. ACCEPTED	576 (100%)	574 (99%)	576 (100%)	576 (100%)	576 (100%)	576 (100%)
WEIGHTED RMS	3.6111E-02	3.6011E-02	8.9331E-04	1.2533E-02	1.2431E-02	6.6651E-05
MEAN RESDUAL	-4.2038E-02	4.1731E-02	-4.7060E-02	2.9880E-03	1.7902E-03	6.5442E-05
STANDARD DEV	3.611	3.601	7.5930E-02	0.1253	0.1243	6.6329E-04

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	210	198	186	180	180	180	180	180	168
NO. ACCEPTED	210 (100%)	198 (100%)	186 (100%)	180 (100%)	180 (100%)	180 (100%)	180 (100%)	180 (100%)	166 (98%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	174	186	204	210	216	204	198	204	198
NO. ACCEPTED	174 (100%)	186 (100%)	204 (100%)	210 (100%)	216 (100%)	204 (100%)	198 (100%)	204 (100%)	198 (100%)

THERE ARE 7 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 7

A H K P Q LAM SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

COMPARE DECK FOR GEOSYNCHRONOUS CASE:

```
CONTROL   COMPARE                                              BS3A        20771
COMPOPT
CMPEPHEM  1102102  940828170335.0      940831170335.0      7.5
END
FIN
```

GEOSYNCHRONOUS COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 577

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	940829	111835.000	4.641092E-03	940831	5605.000	8.159907E-03
CROSS TRACK	940829	51835.000	7.078641E-08	940829	222605.000	3.100871E-04
ALONG TRACK	940828	170335.000	1.198785E-03	940831	170335.000	3.501914E-02
TOTAL	940828	170335.000	5.880411E-03	940831	170335.000	3.581756E-02

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	940828	170335.000	1.860573E-06	940831	170335.000	4.400656E-06
CROSS TRACK	940831	134835.000	1.779926E-11	940830	181105.000	1.410646E-08
ALONG TRACK	940831	115605.000	2.699794E-07	940831	10335.000	5.553332E-07
TOTAL	940828	170335.000	1.901702E-06	940831	170335.000	4.426126E-06

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	6.2625E-03	3.0904E-06
CROSS TRACK	1.6640E-04	9.0059E-09
ALONG TRACK	2.0304E-02	4.1029E-07
TOTAL	2.1249E-02	3.1175E-06

0

NORMAL COMPLETION OF JOB

MOLY Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with mean Keplerian elements
2) Propagate forward one day using DSST to obtain osculating elements
3) Propagate osculating elements forward using Cowell theory to generate truth data

```
CONTROL   EPHEM                                                NSSC        9829
EPOCH                790803.0             234212.0
ELEMENT1  1  6  1    26556.9582           0.6990986            63.173001
ELEMENT2             190.619681           281.59624            13.29315
OUTPUT    1  2  1    790804.0             234212.0             43200.0
ORBTYPE   5  1  1    43200.0              1.0
OGOPT
SPSHPER   5
DRAG      1          1.0
ATMOSDEN        1
SCPARAM              12.5D-6              1250.D0
SOLRAD    1          1.0
POTFIELD  1  5
MAXDEGEQ  1          8.
MAXORDEQ  1          8.
END
FIN
CONTROL   EPHEM                           OUTPUT               NSSC        9829
OUTPUT    1  2  1    790818.0             234212.0             172800.0
ORBTYPE   1  1  1    200.0                                     1.5
OGOPT
DRAG      1          1.0
ATMOSDEN        1
SCPARAM              12.5D-6              1250.D0
SOLRAD    1          1.0
POTFIELD  1  6
MAXDEGEQ  1          21.
MAXORDEQ  1          21.
OUTOPT    1          790804234212.0       790818234212.0       450.
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

GTDS FINAL REPORT

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SATELLITE NAME	NSSC				
SATELLITE NUMBER	9829				
RUN REFERENCE DATE	AUG 3, 1979	0 HRS	0 MINS	0.00000 SECONDS	
RUN EPOCH DATE	AUG 4, 1979	23 HRS	42 MINS	12.00000 SECONDS	
RUN FINAL TIME	AUG 18, 1979	23 HRS	42 MINS	12.00000 SECONDS	
TOTAL TIME OF FLIGHT	14 DAYS	0 HRS	0 MINS	0.00000 SECONDS	
CAUSE OF TERMINATION	SPECIFIED TIME OF FLIGHT REACHED				

END CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	-0.1371825581792548E+05	Y	-0.1119942652170050E+05	Z	0.1774665697145402E+05
VX	0.8606074345775577E+00	VY	-0.1717010361617677E+01	VZ	0.3619315325579901E+01
SMA	0.2655680479867468E+05	ECC	0.6986855599650172E+00	INC	0.6319595630208168E+02
LAN	0.1888106505833530E+03	AP	0.2815323014830572E+03	MA	0.4550424397783793E+02
EA	0.8540744767506621E+02	P	0.1196388453041661E+02	SLR	0.1359279482213544E+05
PR	0.8001948767031005E+04	APR	0.4511166083031836E+05	PH	0.1623810767031005E+04
APH	0.3873352283031836E+05	C3	-0.7504676165332438E+01	TA	0.1309404611544984E+03
RA	0.2192278053194159E+03	DEC	0.4506044124614617E+02	VPA	0.4577045721988872E+02
AZ	0.3967261639170771E+02	RMAG	0.2507112942736071E+05	VMAG	0.4097342207374211E+01

INITIAL CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) MEAN OF 1950.0 -- EARTH EQUATOR

X	-0.1242983594562453E+05	Y	-0.3027625662738115E+04	Z	0.1415477535845710E+04
VX	-0.2488034530421247E+01	VY	-0.3277071176695446E+01	VZ	0.5477775985267707E+01
SMA	0.2657217591471070E+05	ECC	0.6991894044193557E+00	INC	0.6317748516631303E+02
LAN	0.1904823387631476E+03	AP	0.2816075013505303E+03	MA	0.1542883506600653E+02
EA	0.4248634620500351E+02	P	0.1197427310311930E+02	SLR	0.1358194726056090E+05
PR	0.7993192062777778E+04	APR	0.4515115976664363E+05	PH	0.1615054062777778E+04
APH	0.3877302176664363E+05	C3	-0.7500334960889100E+01	TA	0.8547104510736438E+02
RA	0.1936893756438893E+03	DEC	0.6313668242350110E+01	VPA	0.5655372545863263E+02
AZ	0.2699943849605448E+02	RMAG	0.1287132143345407E+05	VMAG	0.6850951836531340E+01

*** SECTIONING SUMMARY ***

NUMBER OF SECTIONS SCHEDULED = 1
NUMBER OF SECTIONS COMPLETED = 1

SECTION	CENTRAL BODY	TIME OF CROSSING				TIME INTO FLIGHT			CAUSE OF CROSSING
			H	M	S	H	M	S	
1	EARTH	AUG 18	23	42	12.000	336	0	0.000	SPECIFIED TIME OF FLIGHT REACHED

*** FILE GENERATION SUMMARY ***

AN ORB-1 FILE HAS BEEN GENERATED
START TIME OF THE FILE = 790804234212.000
END TIME OF THE FILE = 790818234212.000

*** NUMBER OF GTDS ERRORS ENCOUNTERED= 1**

MOLNIYA OPTIMIZED INPUT DECK

```
CONTROL   DATAMGT                                              NSSC          9829
OGOPT
POTFIELD  1  6
END
FIN
CONTROL   DC                                                   NSSC          9829
EPOCH               790804.0             234212.0
ELEMENT1  1  6  1   26572.176            0.699                 63.2
ELEMENT2            190.5                281.6                 15.429
OBSINPUT 15         790804234212.0       790807234212.0
ORBTYPE   5  1  1   43200.0              1.0
DMOPT
OBSDEV   21 22 23   100.                 100.                  100.
OBSDEV   24 25 26   10.                  10.                   10.
END
OGOPT
DRAG      1         1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM             12.5D-6              1250.D0
SOLRAD    1         1.0
SPSRP     0
SPGRVFRC  1  1  3   1.                   1.                    3.
SPZONALS  4  3  8
SPMDAILY  4  4  2
MAXDEGEQ  1         8.
MAXORDEQ  1         8.
STATEPAR  3
STATETAB  1  2  3   4.0                  5.0                   6.0
DRAGPAR   1
DRAGPAR2  1  1
SOLRDPAR  1
SSTESTFL  1  2  0   0.0
SSTAPGFL  1  0  0   1.0                  0.0                   1.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1   1.D-3
END
FIN
CONTROL   EPHEM                          OUTPUT                NSSC          9829
OUTPUT    1  2  1   790818.0             234212.0              172800.0
ORBTYPE   5  1  1   43200.0              1.0
OGOPT
DRAGPAR   0
DRAG      1         1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM             12.5D-6              1250.D0
SOLRAD    1         1.0
SPSRP     0
SOLRDPAR  0
SPGRVFRC  1  1  3   1.                   1.                    3.
SPZONALS  4  3  8
SPMDAILY  4  4  2
MAXDEGEQ  1         8.
MAXORDEQ  1         8.
OUTOPT   21         790804234212.0       790818234212.0        450.
END
FIN
```

SUMMARY OF MOLNIYA OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 4

SATELLITE	NSSC 9829	POSITION ERROR RMS (M)	114.82174	START TIME 790804 234212.000
EPOCH	790804 234212.000	CURRENT WEIGHTED RMS	0.45742789	END TIME 790807 233442.000
COORD. SYSTEM	MEAN OF 1950.0	PREDICTED WEIGHTED RMS	0.51345696	NO. OBS. AVAILABLE 3456
CENTRAL BODY	EARTH	PREVIOUS WEIGHTED RMS	0.51349399	NO. OBS. INCLUDED 3456
		SMALLEST WEIGHTED RMS	0.51349399	NO. OBS. ACCEPTED 3382 97 PCT
		RELATIVE CHANGE IN RMS	0.10918550	
		PENALTY	0.00000000	
		DC HAS CONVERGED		

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	576	576	576	576	576	576
NO. ACCEPTED	502 (87%)	576 (100%)	576 (100%)	576 (100%)	576 (100%)	576 (100%)
WEIGHTED RMS	0.9218	0.4468	0.5014	0.1340	9.2191E-02	0.1024
MEAN RESDUAL	-18.03	-5.572	19.20	-0.2010	-1.0291E-02	-3.9840E-02
STANDARD DEV	90.40	44.34	46.32	1.325	0.9219	1.023

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	24	24	30	48	84	120	240	450	708
NO. ACCEPTED	24 (100%)	24 (100%)	30 (100%)	48 (100%)	84 (100%)	120 (100%)	240 (100%)	448 (99%)	706 (99%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	714	450	234	120	72	48	36	24	30
NO. ACCEPTED	669 (93%)	425 (94%)	234 (100%)	120 (100%)	72 (100%)	48 (100%)	36 (100%)	24 (100%)	30 (100%)

THERE ARE 8 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 8

A H K P Q LAM CSUBD SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

COMPARE DECK FOR MOLNIYA CASE:

```
CONTROL   COMPARE                                              NSSC        9829
COMPOPT
CMPEPHEM  1102102  790807234212.0       790810234212.0       7.5
END
FIN
```

MOLNIYA COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 577

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	790810	104942.000	4.686057E-04	790810	220442.000	3.501438E-01
CROSS TRACK	790808	82712.000	5.364643E-06	790810	45712.000	5.219956E-02
ALONG TRACK	790810	201212.000	1.358405E-03	790810	224212.000	7.213969E-01
TOTAL	790808	121942.000	3.791407E-02	790810	224212.000	7.334274E-01

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	790808	200442.000	1.490001E-09	790810	224942.000	4.816413E-04
CROSS TRACK	790808	44942.000	1.377708E-09	790810	224212.000	1.892690E-05
ALONG TRACK	790810	81212.000	1.646474E-08	790808	224942.000	5.052250E-05
TOTAL	790808	131942.000	1.893925E-06	790810	224942.000	4.820318E-04

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	1.2727E-01	7.3599E-05
CROSS TRACK	2.2510E-02	3.4218E-06
ALONG TRACK	1.7720E-01	1.3041E-05
TOTAL	2.1933E-01	7.4824E-05

```
1                      GTDS  COMPARE  PROGRAM                                     PAGE   16
0
```

NORMAL COMPLETION OF JOB

NEEC Test Case

TRUTH DATA GENERATION

PROCEDURE:

1) Start with 2-card element set
2) Propagate 2-card element set forward using SGP4 to obtain SGP4-based ephemeris
3) Fit Cowell theory to SGP4-based ephemeris
4) Propagate Cowell DC solve-for vector forward to produce truth data

```
CONTROL   EPHEM                                            VANGARD2     59001A
EPOCH                 940826.0          073513.6735
ELEMENT1  8 18  1     11.73921485       0.1522640          32.8834
ELEMENT2              251.8592          10.8368            352.1515
ELEMENT3              -0.00000000       0.000000           0.000154
OUTPUT    1  2  1     940905.0          073514.0           86400.0
ORBTYPE  14  1  8     1.0
OGOPT
POTFIELD  1  7
OUTOPT    1           940826073514.0    940905073514.0     450.0
END
FIN
```

SGP4 EPHEMERIS OUTPUT SUMMARY:

GTDS FINAL REPORT

PAGE 13

SATELLITE NAME	VANGARD2			
SATELLITE NUMBER	59001			
RUN REFERENCE DATE	AUG 26, 1994	0 HRS	0 MINS	0.00000 SECONDS
RUN EPOCH DATE	AUG 26, 1994	7 HRS	35 MINS	13.67350 SECONDS
RUN FINAL TIME	SEPT 5, 1994	7 HRS	35 MINS	14.00000 SECONDS
TOTAL TIME OF FLIGHT	10 DAYS	0 HRS	0 MINS	0.32650 SECONDS
CAUSE OF TERMINATION	SPECIFIED TIME OF FLIGHT REACHED			

END CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) — MEAN OF 1950.0 -- EARTH EQUATOR

X	0.4226905530387705E+04	Y	0.7668401667445838E+04	Z	-0.2551272994307648E+04
VX	-0.4861278344213523E+01	VY	0.2411752650711627E+01	VZ	-0.3040089571074028E+01
SMA	0.8181674036773987E+04	ECC	0.1520921345305507E+00	INC	0.3288983668642646E+02
LAN	0.2150862746053120E+03	AP	0.6636140824147962E+02	MA	0.1332440193797609E+03
EA	0.1389650806767234E+03	P	0.2045839426995563E+01	SLR	0.7992415410708262E+04
PR	0.6937305768487844E+04	APR	0.9426042305060129E+04	PH	0.5591707684878438E+03
APH	0.3047907305060129E+04	C3	-0.2435936693446952E+02	TA	0.1444016201663212E+03
RA	0.6164386322942167E+02	DEC	-0.1612604086662168E+02	VPA	0.8423117145710005E+02
AZ	0.1190602065290431E+03	RMAG	0.9120312967737114E+04	VMAG	0.6220186707225738E+01

INITIAL CONDITIONS

CENTRAL BODY IS EARTH (INERTIAL SYSTEM) — "NORAD" TRUE OF REF. -- EARTH EQUATOR

X	-0.2158590909184290E+04	Y	-0.6607917004462769E+04	Z	0.3943505275263057E+01
VX	0.6544250260129505E+01	VY	-0.1923627551859584E+01	VZ	0.4407890047245081E+01
SMA	0.8181027891766687E+04	ECC	0.1522639999999998E+00	INC	0.3288339999999999E+02
LAN	0.2518591999999999E+03	AP	0.1083680000000000E+02	MA	0.3521514999999999E+03
EA	0.3507490211595139E+03	P	0.2045597077540084E+01	SLR	0.7991356276595909E+04
PR	0.6935351860854726E+04	APR	0.9426703922678649E+04	PH	0.5572168608547254E+03
APH	0.3048568922678649E+04	C3	-0.2436129085937650E+02	TA	0.3492230657582670E+03
RA	0.2519094739042656E+03	DEC	0.3250298192318978E-01	VPA	0.9141873484191045E+02
AZ	0.5711661425979332E+02	RMAG	0.6951553596306017E+04	VMAG	0.8121394528902080E+01

*** SECTIONING SUMMARY ***

NUMBER OF SECTIONS SCHEDULED = 1
NUMBER OF SECTIONS COMPLETED = 1

SECTION	CENTRAL BODY	TIME OF CROSSING				TIME INTO FLIGHT			CAUSE OF CROSSING
			H	M	S	H	M	S	
1	EARTH	SEPT 5	7	35	14.000	240	0	0.326	SPECIFIED TIME OF FLIGHT REACHED

*** FILE GENERATION SUMMARY ***

AN ORB-1 FILE HAS BEEN GENERATED
START TIME OF THE FILE = 940826073514.000
END TIME OF THE FILE = 940905073514.000

*** NUMBER OF GTDS ERRORS ENCOUNTERED= 0**

TRUTH DATA GENERATION

COWELL DC & EPHEM DECK (FIT TO SGP4-BASED EPHEMERIS) TO GENERATE TRUTH DATA:

```
                                                                 VANGARD2     59001A
CONTROL    DC
EPOCH                      940826.0              073513.6735
ELEMENT1   1   2   1       8183.787              0.153069              32.7
ELEMENT2                   251.2                 11.1                  352.022
OBSINPUT 15                940826073514.0        940831073514.0
ORBTYPE    2   1   1       60.0
DMOPT
OBSDEV     21 22 23        500.0                 500.0                 500.0
OBSDEV     24 25 26        50.0                  50.0                  50.0
END
DCOPT
PRINTOUT   1       4
CONVERG    30      1       1.D-3
END
OGOPT
DRAG       1               1.0
ATMOSDEN           1
SCPARAM                    1.D-6                 100.D0
SOLRAD     1               1.0
POTFIELD   1   2
MAXDEGEQ   1               21.0
MAXORDEQ   1               21.0
STATEPAR   1
STATETAB   1   2   3       4.0                   5.0                   6.0
DRAGPAR    1
SOLRDPAR   1
END
FIN
CONTROL    EPHEM                                  OUTPUT               VANGARD2     59001A
OUTPUT     1   2   1       940905.0              073514.0              86400.0
ORBTYPE    2   1   1       60.0
OGOPT
DRAG       1               1.0
DRAGPAR    0
ATMOSDEN           1
SCPARAM                    1.D-6                 100.D0
SOLRAD     1               1.0
SOLRDPAR   0
POTFIELD   1   2
MAXDEGEQ   1               21.0
MAXORDEQ   1               21.0
OUTOPT     21              940826073514.0        940905073514.0        450.0
END
FIN
```

TRUTH DATA GENERATION

COWELL EPHEMERIS OUTPUT SUMMARY:

```
                                          ITERATION NUMBER  6

                                   ************************************************
                                   *  POSITION ERROR RMS (M)     960.56962        *
SATELLITE       VANGARD2    59001  *  CURRENT WEIGHTED RMS       1.1041600        *  START TIME   940826  74244.000
                                   *  PREDICTED WEIGHTED RMS     1.1066222        *
EPOCH           940826  73513.674  *  PREVIOUS WEIGHTED RMS      1.1072310        *  END TIME     940831  73514.000
                                   *  SMALLEST WEIGHTED RMS      1.1072310        *
COORD. SYSTEM   MEAN OF 1950.0     *  RELATIVE CHANGE IN RMS    2.77354456E-03   *  NO. OBS. AVAILABLE  5760
                                   *  PENALTY                   0.00000000        *
CENTRAL BODY    EARTH              *  DC HAS CONVERGED                            *  NO. OBS. INCLUDED   5760
                                   *                                              *
                                   ************************************************  NO. OBS. ACCEPTED 5757 99 PCT

                                        OBSERVATION SUMMARY BY TYPE

TYPE            X            Y            Z            XDOT         YDOT         ZDOT
TOTAL NO.       960          960          960          960          960          960
NO. ACCEPTED    960 (100%)   960 (100%)   960 (100%)   960 (100%)   960 (100%)   957 ( 99%)
WEIGHTED RMS 0.5797          1.127        1.444        0.3973       0.7494       1.706
MEAN RESDUAL -119.6          472.0        327.2        6.770        9.954        54.11
STANDARD DEV  264.1          307.7        643.5        18.68        36.12        65.94

                                   OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL
0INTERVAL       00-20        20-40        40-60        60-80        80-100       100-120      120-140      140-160      160-180
 TOTAL NO.      240          234          264          282          312          348          378          408          432
 NO. ACCEPTED   240 (100%)   234 (100%)   264 (100%)   282 (100%)   312 (100%)   348 (100%)   378 (100%)   408 (100%)   432
(100%)
0INTERVAL      180-200      200-220      220-240      240-260      260-280      280-300      300-320      320-340      340-360
 TOTAL NO.      426          408          384          342          300          276          252          246          228
 NO. ACCEPTED   426 (100%)   408 (100%)   384 (100%)   339 ( 99%)   300 (100%)   276 (100%)   252 (100%)   246 (100%)   228
(100%)

                                        THERE ARE  8 SOLVE PARAMETERS

 NUMBER OF DYNAMIC SOLVE PARAMETERS =  8
 X          Y          Z          VX          VY          VZ          RHO1          SOLRAD

 NUMBER OF STATION LOCATIONS BEING SOLVED FOR =  0

 NUMBER OF BIASES BEING SOLVED FOR =  0

                                        *** FILE GENERATION SUMMARY ***

                         NO FILES HAVE BEEN GENERATED

                         * NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE =     6 *
```

NEEC OPTIMIZED INPUT DECK

```
CONTROL   DC                                                   VANGARD2     59001A
EPOCH                   940826.0             073513.6735
ELEMENT1  3  6  1       8177.913             0.1522640            32.8834
ELEMENT2                251.8592             10.8368              352.1515
OBSINPUT 15             940826073514.0       940829073514.0
ORBTYPE   5  1  1       43200.0              1.0
DMOPT
OBSDEV    21 22 23      100.                 100.                 100.
OBSDEV    24 25 26      10.                  10.                  10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1       1.D-4
END
OGOPT
DRAG      1             1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM                 1.D-6                100.D0
SOLRAD    1             1.0
SPSRP     0
SPGRVFRC  1  1  3       3.0                  1.0                  3.0
SPZONALS  6  5 13
SPMDAILY  6  6  4
POTFIELD  1  2
MAXDEGEQ  1             21.
MAXORDEQ  1             21.
RESONPRD                86400.0
STATEPAR  3
STATETAB  1  2  3       4.0                  5.0                  6.0
DRAGPAR   1
DRAGPAR2  1  1
SOLRDPAR  1
SSTESTFL  1  2  0       0.0
SSTAPGFL  1  0  0       1.0                  0.0                  1.0
END
FIN
CONTROL   EPHEM                              OUTPUT               VANGARD2     59001A
OUTPUT    1  2  1       940905.              073514.0             86400.0
ORBTYPE   5  1  1       43200.0              1.0
OGOPT
DRAGPAR   0
DRAG      1             1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM                 1.D-6                100.D0
SOLRAD    1             1.0
SPSRP     0
SOLRDPAR  0
SPGRVFRC  1  1  3       3.0                  1.0                  3.0
SPZONALS  6  5 13
SPMDAILY  6  6  4
POTFIELD  1  2
MAXDEGEQ  1             21.
MAXORDEQ  1             21.
RESONPRD                86400.0
OUTOPT   21             940826073514.0       940905073514.0       450.0
END
FIN
```

SUMMARY OF NEEC OPTIMIZED DSST FIT TO COWELL TRUTH:

ITERATION NUMBER 6

```
                                   ************************************************
                                   *  POSITION ERROR RMS (M)      69.419240       *
SATELLITE      VANGARD2    59001   *  CURRENT WEIGHTED RMS        0.37449436      *  START TIME  940826  74244.000
                                   *  PREDICTED WEIGHTED RMS      0.37647487      *
EPOCH          940826  73513.674   *  PREVIOUS WEIGHTED RMS       0.37650718      *  END TIME    940829  73514.000
                                   *  SMALLEST WEIGHTED RMS       0.37650718      *
COORD. SYSTEM  MEAN OF 1950.0      *  RELATIVE CHANGE IN RMS      5.34604546E-03  *  NO. OBS. AVAILABLE  3456
                                   *  PENALTY                     0.00000000      *
CENTRAL BODY   EARTH               *  DC HAS CONVERGED                            *  NO. OBS. INCLUDED   3456
                                   *                                              *
                                   ************************************************  NO. OBS. ACCEPTED 3443 99 PCT
```

OBSERVATION SUMMARY BY TYPE

TYPE	X	Y	Z	XDOT	YDOT	ZDOT
TOTAL NO.	576	576	576	576	576	576
NO. ACCEPTED	568 (98%)	572 (99%)	576 (100%)	576 (100%)	575 (99%)	576 (100%)
WEIGHTED RMS	0.4409	0.3934	0.3666	0.3263	0.3209	0.3134
MEAN RESDUAL	-0.8460	-1.781	2.432	-4.2900E-02	3.5866E-02	-0.2093
STANDARD DEV	44.08	39.30	36.58	3.263	3.209	3.127

OBSERVATION SUMMARY BY 20 DEGREE TRUE ANOMALY INTERVAL

0INTERVAL	00-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180
TOTAL NO.	150	144	156	168	198	204	222	246	252
NO. ACCEPTED	149 (99%)	144 (100%)	156 (100%)	168 (100%)	198 (100%)	204 (100%)	221 (99%)	245 (99%)	251 (99%)

0INTERVAL	180-200	200-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360
TOTAL NO.	252	240	234	204	180	168	156	150	132
NO. ACCEPTED	248 (98%)	239 (99%)	231 (98%)	203 (99%)	180 (100%)	168 (100%)	156 (100%)	150 (100%)	132 (100%)

THERE ARE 8 SOLVE PARAMETERS

NUMBER OF DYNAMIC SOLVE PARAMETERS = 8

A H K P Q LAM CSUBD SOLRAD

NUMBER OF STATION LOCATIONS BEING SOLVED FOR = 0

NUMBER OF BIASES BEING SOLVED FOR = 0

*** FILE GENERATION SUMMARY ***

NO FILES HAVE BEEN GENERATED

* NUMBER OF GTDS ERRORS ENCOUNTERED TO DATE = 0 *

COMPARE DECK FOR NEEC:

```
CONTROL   COMPARE                                                      VANGARD2    59001A
COMPOPT
CMPEPHEM  1102102  940829073514.0        940901073514.0        7.5
END
FIN
```

NEEC COMPARE SUMMARY:

EPHEMERIS COMPARISON SUMMARY REPORT

Number of Points Compared 577

	MINIMUM POSITION DIFFERENCE			MAXIMUM POSITION DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km)	YYMMDD	HHMMSS.SSS	(km)
RADIAL	940829	155014.000	4.082393E-06	940901	43514.000	1.103580E-01
CROSS TRACK	940829	84244.000	6.979701E-05	940831	130514.000	2.553895E-01
ALONG TRACK	940829	95014.000	9.159481E-06	940831	194244.000	4.969624E-01
TOTAL	940831	164244.000	1.110800E-02	940831	194244.000	5.081243E-01

	MINIMUM VELOCITY DIFFERENCE			MAXIMUM VELOCITY DIFFERENCE		
	YYMMDD	HHMMSS.SSS	(km/sec)	YYMMDD	HHMMSS.SSS	(km/sec)
RADIAL	940829	115014.000	3.964064E-08	940901	42744.000	3.010421E-04
CROSS TRACK	940830	42014.000	1.722035E-07	940901	25014.000	2.334248E-04
ALONG TRACK	940830	145014.000	3.795844E-07	940831	190514.000	1.350620E-04
TOTAL	940829	150514.000	3.683908E-06	940831	195744.000	3.353047E-04

	POSITION RMS	VELOCITY RMS
	(km)	(km/sec)
RADIAL	5.1535E-02	1.2705E-04
CROSS TRACK	1.0831E-01	9.0419E-05
ALONG TRACK	1.8288E-01	5.1923E-05
TOTAL	2.1871E-01	1.6436E-04

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NORMAL COMPLETION OF JOB

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